National Park Service
U.S. Department of the Interior

Non-native Plant Mapping at Montezuma Castle and Tuzigoot National Monuments

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A cooperative project by:

Sonoran Desert Network
Inventory and Monitoring Program
National Park Service

and

School of Natural Resources
The University of Arizona

1 April 2004

SONORAN DESERT NETWORK
Inventory and Monitoring Program

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Acknowledgements

Thanks to Kathy Davis and the staff at Montezuma Castle and Tuzigoot National Monuments for their support of this project. Much appreciation also goes to Melissa Mauzy and Meg Quinn for field data collection and plant identification. Kristen Beaupre performed invaluable data management and manipulation tasks, and Amy Tendick played a large role in final map production. Thanks also go to the Sonoran Desert Inventory and Monitoring Program for project support and facilities.

1. Introduction

Biological invasions by nonnative organisms are believed to be a major source of change affecting ecological systems. Nonnative plant species' negative impacts on biological communities include alteration of biogeochemical cycles (Vitousek, and Walker 1989, Le Maitre et al. 1996), modification of fire and other disturbance regimes (Mack and D'Antonio 1998), reduction of species richness (Bock et al. 1986), and extinctions of native species (Pimm et al. 1995). Invasion by nonnative species is recognized internationally as a major threat to global biodiversity, second only to habitat loss (Vitousek et al. 1997, Wilcove et al. 1998).

"Exotic species" are those species that occupy or could occupy park lands directly or indirectly as the result of deliberate or accidental human activities (USDI 2001). Exotic species are also commonly referred to as non-native, alien, or invasive species. Because an exotic species did not evolve in concert with the species native to the place, the exotic species is not a natural component of the natural ecosystem at that place.

According to NPS Management Policies (2001), "(e)xotic species will not be allowed to displace native species if displacement can be prevented." In addition, these policies state that "high priority will be given to managing exotic species that have, or potentially could have, a substantial impact on park resources, and that can reasonably be expected to be successfully controllable." The first step in managing nonnative plants determining their presence, distribution, and abundance. Through this project, the spatial distribution of 50 key nonnative plant species was mapped at Montezuma Castle and Tuzigoot National Monuments in central Arizona.

The information collected through this effort will:

- increase the ability of resource managers to analyze and prioritize invasive plant management needs, enhancing the time and cost-effectiveness of management actions;
- serve as a baseline for long-term monitoring, assist with the evaluation of changes in alien plant populations over time and detecting new infestations; and
- serve as a critical tool for increasing public and political awareness and education on invasive plant issues.

In addition, the data collected through this study will provide the basis for an exotic plant management plan for Montezuma Castle and Tuzigoot National Monuments.

1.1 Project Goals

The goals of this project were:

1) to map the spatial location, distribution and abundance of 50 nonnative plants in Montezuma Castle and Tuzigoot National Monuments; and
2) to test the efficacy of roaming surveys for nonnative plant mapping using a modified version of the "Beyond NAWMA" (Stohlgren et al. no date) weed mapping standards suggested by the North American Weed Management Association (NAWMA) in these National Parks.

1.2 Study Area

Located midway between the cities of Flagstaff and Phoenix along Interstate 17, Montezuma Castle National Monument (MCNM) occupies 671 hectares of the upper Verde Valley in central Arizona. MCNM is comprised of two comparably sized units located approximately 7 km apart: the Castle Unit (containing the primary ruins and the park visitor center), and the Well Unit, both located along Beaver Creek. The Castle unit preserves a five-story, 20-room prehistoric cliff dwelling, built some 600 years ago by Sinagua culture. The Well unit preserves a unique limestone sinkhole (or "well") located on a mesa overlooking Wet Beaver Creek, a perennial stream. The Well is ringed with additional ruins, evidently due to the perennial water source. In this report, MCCU will be used to denote Montezuma Castle-Castle Unit; MCWU will refer to Montezume Castle-Well Unit.

Tuzigoot National Monument (TNM), located 35 kilometers west of Montezuma Castle NM, was established in 1939 to protect Tuzigoot Pueblo, a 110-room multistory structure build by the Sinaguan Culture. Tavasci Marsh, an adjacent 130-hectare wetland, has been proposed for incorporation into park boundaries.

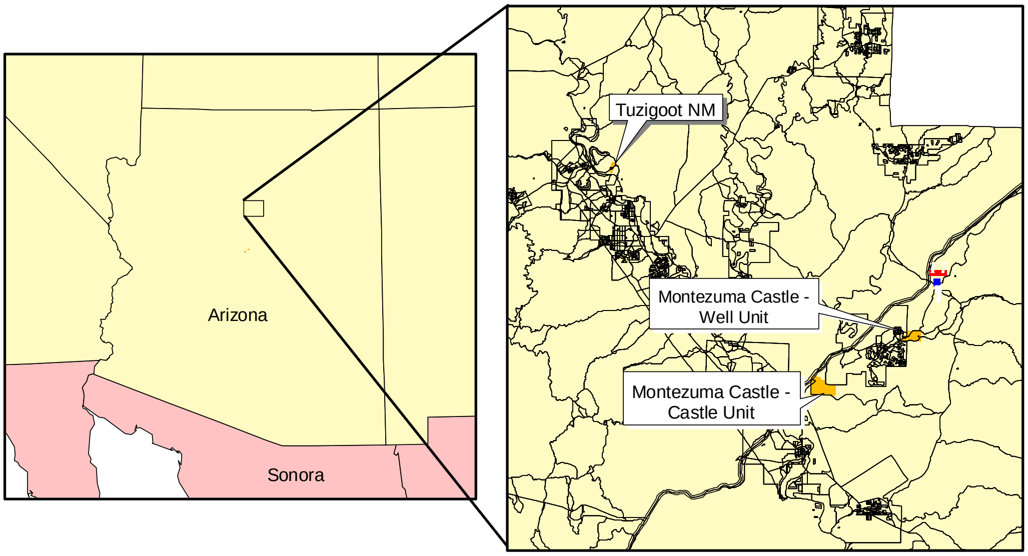


Figure 1. Location of Montezuma Castle and Tuzigoot National Monuments in Arizona.

2. Methods

The location and abundance of nonnative species were mapped at Montezuma Castle and Tuzigoot National Monuments following the North American Invasive Plant Mapping Standards (NAWMA 2002) and the "Beyond NAWMA" guidelines suggested by researchers at the United States Geological Survey and Colorado State University (Stohlgren et al. no date). Because the parks to be mapped were small (less than 500 ha), an intensive mapping method was undertaken. Individual target plants were mapped as points and invaded regions were mapped as polygons using handheld computers and global positioning systems (GPS) units.

2.1 Roaming Surveys

Fifty weed species identified by the National Park Service as problematic species within Arizona were the target for this mapping effort. Spatial location, distribution, and abundance of these plants were recorded as ArcView shapefiles (.shp) using Compaq iPAQ 3950 pocket PCs equipped with HGIS software (www.starpal.com) attached to Garmin III global positioning system (GPS) units. Two University of Arizona researchers identified locations of target species via walking surveys. Target species individuals were mapped as points; patches larger than 3 m in diameter (spatial resolution of GPS units) were mapped as polygons. Up to five species were recorded for each polygon, in descending order of invasion by target species. Abundance of target species was recorded for polygons in the following cover classes:

- <1%
- 1-5%
- 6-25%
- 26-50%
- 51-75%
- 76-95%
- 96-100%

Data collection surveys took place on 21-25 July, 28 July - 1 Aug, 11-15 Aug, and 18-22 Aug 2003. Data were collected following the North American Invasive Plant Mapping Standards (NAWMA 2002), including the following fields:

- collection date
- examiner
- plant name (Genus, species)
- canopy cover
- location (Universal Transverse Mercator coordinates)

Data files were manipulated in the office to incorporate several additional data fields suggested by the North American Invasive Plant Mapping Standards (NAWMA 2002), including:

- NPS Region (Intermountain Region, abbreviated as IMR)
- NPS Inventory & Monitoring Network (Sonoran Desert Network, abbreviated as SODN)
- Park Unit (MCCU, MCWU, or TNM)
- State (AZ)
- County (Yavapai)
- Ownership (NPS)
- Type of survey (observed-mapped)
- Authority (following Kearney and Peebles1951)
- Plant code (following the Natural Resources Conservation Service's PLANTS database – http://plants.usda.gov/plants/index.html)
- Area of polygons

Data files were split and merged to generate individual ArcView shapefiles by species by park unit, with point and polygons appearing in separate files.

2.2 Beyond NAWMA Sampling

In the "Beyond NAWMA" guidelines, Stohlgren et al. (no date) recommend supplementing roaming surveys with randomly located circular plot sampling to estimate spatial bias and accuracy. Approximately ten percent of field resources were used to perform circular plot sampling.

Twenty-nine circular plots were sampled within Tuzigoot National Monument, providing excellent coverage of this small park, at 17.5 ha (Figure 2). Equal coverage was initially planned for each unit of Montezuma Castle National Monument, however due to time constraints, twelve points were sampled in each unit (Figure 2). The circular plots were 7.32 m (24 ft) in diameter, encompassing three 1 m^2 quadrats (Figure 3). Percent cover of all species were recorded within the 1 m^2 quadrats to the nearest 1%. Percent cover of all ground variables (rock, leaf litter, dead wood, dung) was also recorded to the nearest 1%. All additional species observed within the entire circular plot were also recorded. A sample data sheet is provided in Appendix A. Data from all circular plot data sheets were entered into an Access database.

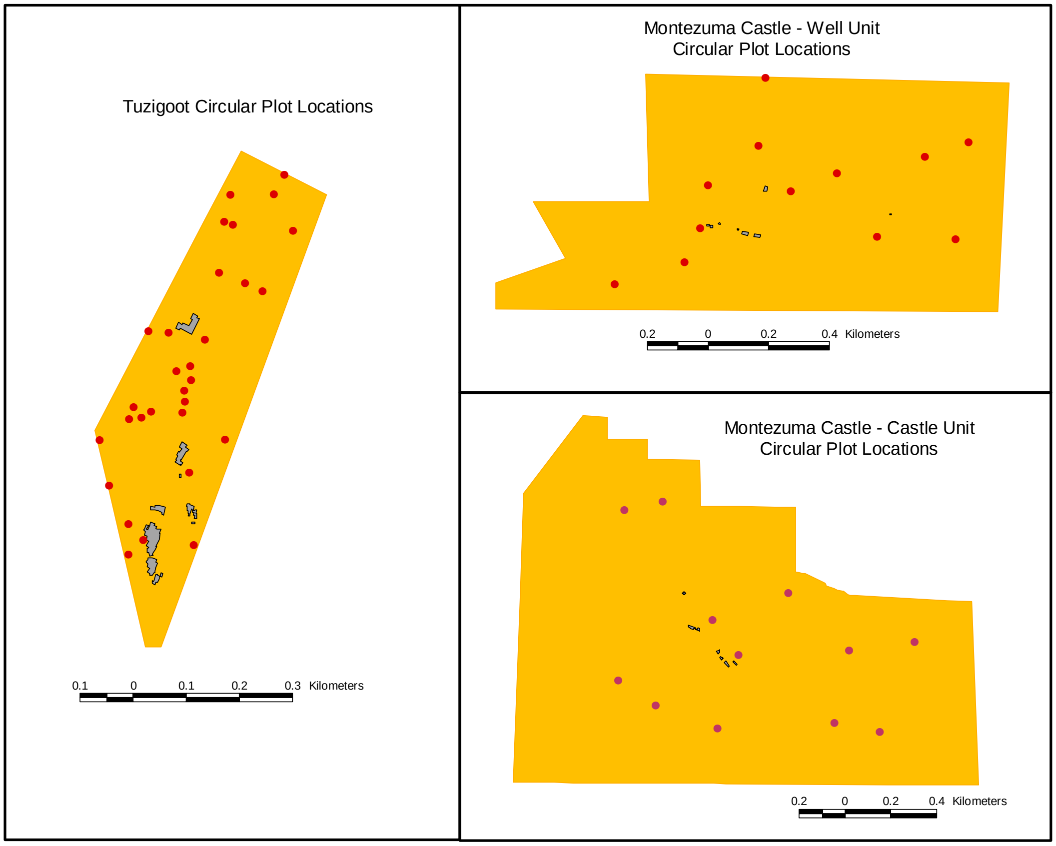


Figure 3. Location of circular plots in three park units.

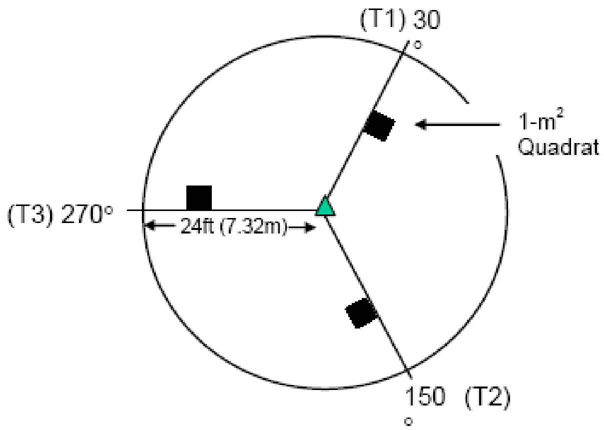


Figure 2. Circular plot layout used for spatial bias and accuracy assessment.

3. Results

3.1 Roaming Surveys

Of the 50 target species for this project, thirty-three species were encountered during roaming surveys in at least one of the three park units and mapped as points or polygons (Table 1). Maps of each species by park unit appear in Appendix B.

Table 1. Target species occurrences mapped by park unit summer 2003.

Species	MCCU Point Occurrences	MCCU Polygons Occurrences	MCWU Point Occurrences	MCWU Polygon Occurrences	TNM Point Occurrences	TNM Polygon Occurrences	**Total Point Occurrences**	**Total Polygon Occurrences**
Avena fatua	9	7	0	2	0	0	**9**	**9**
Boerhavia coccinea	1	0	10	6	0	0	**11**	**6**
Brassica tournefortii	1	0	0	1	0	0	**1**	**1**
Bromus madritensis ssp. rubens	52	49	46	18	387	29	**485**	**96**
Bromus rigidus	65	36	52	14	0	0	**117**	**50**
Bromus tectorum	72	23	4	12	0	0	**76**	**35**
Centaurea melitensis	3	3	0	3	0	0	**3**	**6**
Centaurea solstitialis	0	0	0	1	0	0	**0**	**1**
Conyza canadensis	0	0	5	2	0	0	**5**	**2**
Cynodon dactylon	70	3	42	4	0	0	**112**	**7**
Cyperus esculentus	3	0	3	0	0	0	**6**	**0**
Digitaria sanguinalis	68	0	33	0	0	0	**101**	**0**
Echinochloa crus-galli	6	0	4	0	0	0	**10**	**0**
Eragrostis curvula	0	0	1	0	0	0	**1**	**0**
Erodium cicutarium	0	18	1	8	0	0	**1**	**26**
Helianthus annuus	2	0	5	1	0	0	**7**	**1**
Heterotheca subaxillaris	2	0	1	0	0	0	**3**	**0**
Hordeum spp.	8	28	0	9	0	0	**8**	**37**
Lactuca serriola	17	0	26	2	0	0	**43**	**2**
Marrubium vulgare	4	5	27	12	0	1	**31**	**18**
Melilotus albus	81	0	28	0	0	0	**109**	**0**
Polygonum aviculare	6	0	0	0	0	0	**6**	**0**
Polypogon monspeliensis	116	5	22	0	0	0	**138**	**5**
Rumex crispus	0	0	2	0	0	0	**2**	**0**
Salsola spp.	3	2	1	2	0	0	**4**	**4**
Schismus barbatus	2	13	0	4	0	0	**2**	**17**
Setaria viridus	4	0	4	0	0	0	**8**	**0**
Sisymbrium irio	18	45	39	16	248	32	**305**	**93**
Sorghum halepense	72	3	17	2	0	0	**89**	**5**
Tamarix spp.	56	1	16	0	0	0	**72**	**1**
Tribulus terrestris	0	0	0	2	0	0	**0**	**2**
Verbascum thapsus	0	0	1	0	0	0	**1**	**0**
Xanthium strumarium	0	3	35	0	0	0	**35**	**3**

The area of land affected by each target species is provided in Table 2. These values represent all land area within park units invaded by these plants at 5% cover or higher, measured through the roaming surveys. Therefore, these values represent distribution of nonnative plant cover, but do not reflect the intensity of invasion. Points were estimated to represent 0.5 m^2. Figure 4 displays these data, highlighting *Bromus madritensis ssp. rubens* as the most widely distributed species across the three park units. *Erodium cicutarium*, *Bromus tectorum*, *Schismus barbatus*, *Hordeum spp.*, and *Avena fatua* also occur widely in MCCU and MCWU. *Sisimbrium irio* is rather widely distributed in MCWU and TNM.

Table 2. Portion of park units affected by target species measured through roaming surveys.

Species	MCCU land area affected (ha)	Percent of MCCU affected	MCWU land area affected (ha)	Percent of MCWU affected	TNM land area affected (ha)	Percent of TNM affected	**Total area affected (ha)**
Avena fatua	21.71	9.4%	17.75	17.2%	-	-	**39.46**
Boerhavia coccinea	T	T	11.01	10.7%	-	-	**11.01**
Brassica tournefortii	T	T	1.36	1.3%	-	-	**1.36**
B. madritensis ssp. rubens	221.79	95.8%	86.31	83.7%	2.33	13.3%	**310.43**
B. rigidus	T	T	31.22	30.3%	-	-	**31.22**
B. tectorum	169.29	73.1%	54.42	52.8%	-	-	**223.71**
Centaurea melitensis	0.34	0.1%	7.66	7.4%	-	-	**8.00**
C. solstitialis	-	-	1.29	1.3%	-	-	**1.29**
Conyza canadensis	-	-	8.90	8.6%	-	-	**8.90**
Cynodon dactylon	0.25	0.1%	5.97	5.8%	-	-	**6.22**
Cyperus esculentus	T	T	T	T	-	-	**T**
Digitaria sanguinalis	T	T	T	T	-	-	**T**
Echinochloa crus-galli	T	T	T	T	-	-	**T**
Eragrostis curvula	-	-	T	T	-	-	**T**
Erodium cicutarium	175.05	75.6%	64.04	62.1%	-	-	**239.09**
Helianthus annuus	T	T	2.23	2.2%	-	-	**2.23**
Heterotheca subaxillaris	T	T	T	T	-	-	**T**
Hordeum spp.	47.53	20.5%	43.50	42.2%	-	-	**91.03**
Lactuca serriola	T	T	3.93	3.8%	-	-	**3.93**
Marrubium vulgare	0.82	0.4%	17.81	17.3%	0.07	0.4%	**18.70**
Melilotus albus	T	T	T	T	-	-	**T**
Polygonum aviculare	T	T	-	-	-	-	**T**
Polypogon monspeliensis	0.01	T	T	T	-	-	**0.01**
Rumex crispus	-	-	T	T	-	-	**T**
Salsola spp.	0.69	0.3%	2.85	2.8%	-	-	**3.54**
Schismus barbatus	109.47	47.3%	39.21	38.0%	-	-	**148.68**
Setaria viridus	T	T	T	T	-	-	**T**
Sisymbrium irio	T	T	45.32	44.0%	2.80	15.9%	**48.12**
Sorghum halepense	0.13	0.1%	2.03	2.0%	-	-	**2.16**
Tamarix spp.	0.07	T	T	T	-	-	**0.07**
Tribulus terrestris	-	-	0.92	0.9%	-	-	**0.92**
Verbascum thapsus	-	-	T	T	-	-	**T**
Xanthium strumarium	0.11	T	T	T	-	-	**0.11**

T denotes area < .01 ha or percent < 0.1%.
- denotes species not observed.

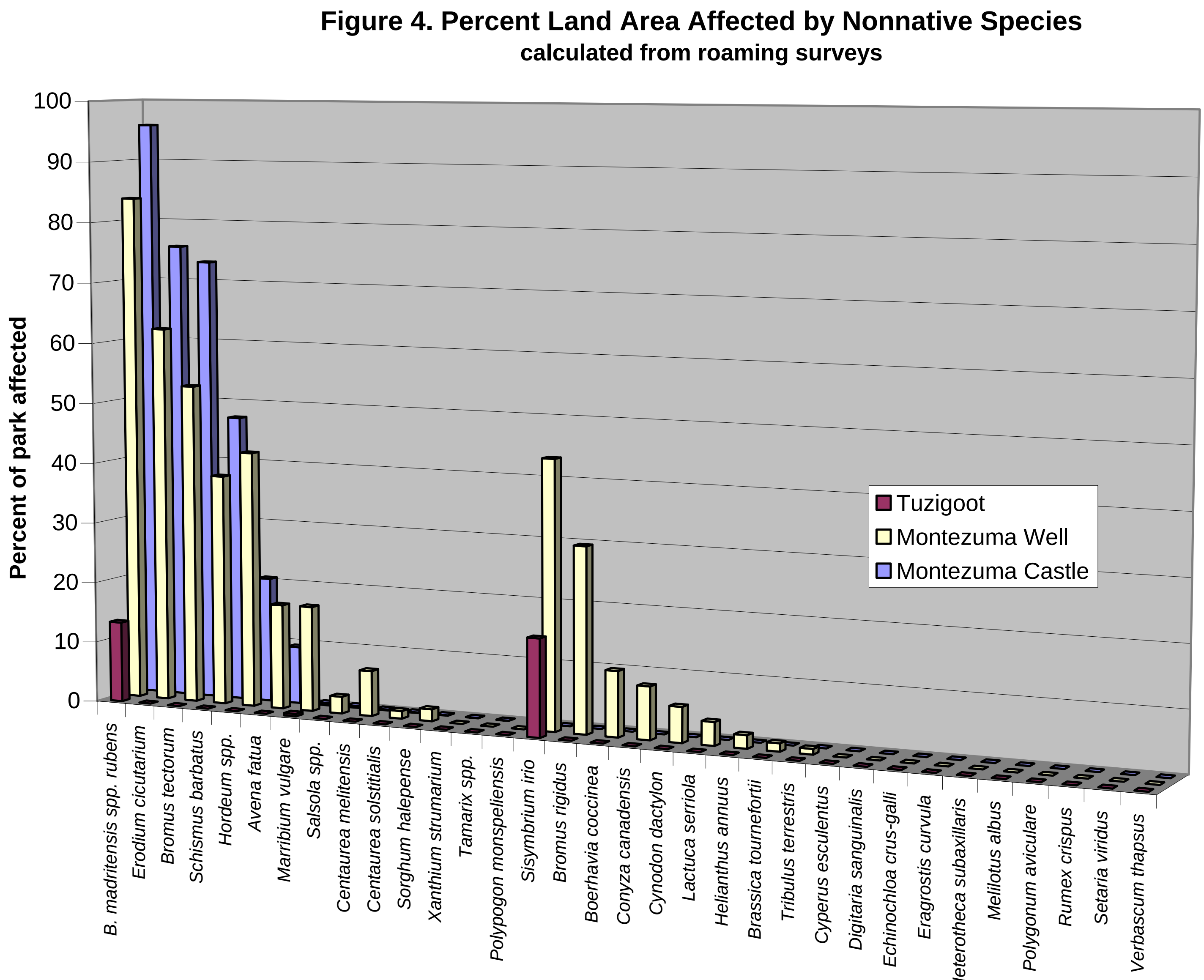


Figure 4. Percent Land Area Affected by Nonnative Species
calculated from roaming surveys
Percent of park affected
100
90
80
70
60
50
40
30
20
10
0
Tuzigoot
Montezuma Well
Montezuma Castle
B. madritensis spp. rubens
Erodium cicutarium
Bromus tectorum
Schismus barbatus
Hordeum spp.
Avena fatua
Marribium vulgare
Salsola spp.
Centaurea melitensis
Centaurea solstitialis
Sorghum halepense
Xanthium strumarium
Tamarix spp.
Polypogon monspeliensis
Sisymbrium irio
Bromus rigidus
Boerhavia coccinea
Conyza canadensis
Cynodon dactylon
Lactuca serriola
Helianthus annuus
Brassica tournefortii
Tribulus terrestris
Cyperus esculentus
Digitaria sanguinalis
Echinochloa crus-galli
Eragrostis curvula
Heterotheca subaxillaris
Melilotus albus
Polygonum aviculare
Rumex crispus
Setaria viridus
Verbascum thapsus

Using the roaming survey data, the *actual* land area *infested* by each target species was also calculated. Actual infested area was calculated using polygon data by multiplying the cover class midpoint by the polygon's area. For example, a polygon 1.5 ha in area estimated at 25-50% cover would represent 0.5625 ha (1.5 * .375 = 0.5625 ha) infested. Points were estimated to represent 0.5 m^2. Species totals by park unit appear in Table 3. These values are much smaller than those in Table 2 because these represent total hectares *completely* infested by the target species. Figure 5 displays these data.

Table 3. Hectares entirely infested by target species measured by roaming surveys.

Species	MCCU land area infested (ha)	MCWU land area infested (ha)	TNM land area infested (ha)	**Total area infested (ha)**
Avena fatua	0.13	0.09	-	**0.22**
Boerhavia coccinea	T	0.13	-	**0.13**
Brassica tournefortii	T	-	-	**T**
Bromus rigidus	0.01	5.07	-	**5.08**
B. madritensis ssp. rubens	35.24	20.23	0.68	**56.15**
Bromus tectorum	10.55	1.16	-	**11.71**
Centaurea melitensis	T	-	-	**T**
Centaurea solstitialis	-	0.16	-	**0.16**
Conyza canadensis	-	0.37	-	**0.37**
Cynodon dactylon	0.12	0.24	-	**0.36**
Cyperus esculentus	T	T	-	**T**
Digitaria sanguinalis	0.01	T	-	**0.01**
Echinochloa crus-galli	T	T	-	**T**
Eragrostis curvula	-	T	-	**T**
Erodium cicutarium	49.49	18.13	-	**67.62**
Helianthus annuus	T	0.01	-	**0.01**
Heterotheca subaxillaris	T	T	-	**T**
Hordeum spp.	9.97	0.93	-	**10.90**
Lactuca serriola	T	0.12	-	**0.12**
Marrubium vulgare	T	0.94	T	**0.94**
Melilotus albus	0.01	T	-	**0.01**
Polygonum aviculare	T	-	-	**T**
Polypogon monspeliensis	0.01	T	-	**0.01**
Rumex crispus	-	T	-	**T**
Salsola spp.	0.01	0.09	-	**0.10**
Schismus barbatus	7.88	0.52	-	**8.40**
Setaria viridus	T	T	-	**T**
Sisymbrium irio	0.85	0.77	0.86	**2.48**
Sorghum halepense	0.01	0.32	-	**0.33**
Tamarix spp.	7.20	T	-	**7.20**
Tribulus terrestris	-	-	-	**T**
Verbascum thapsus	-	T	-	**T**
Xanthium strumarium	-	T	-	**T**

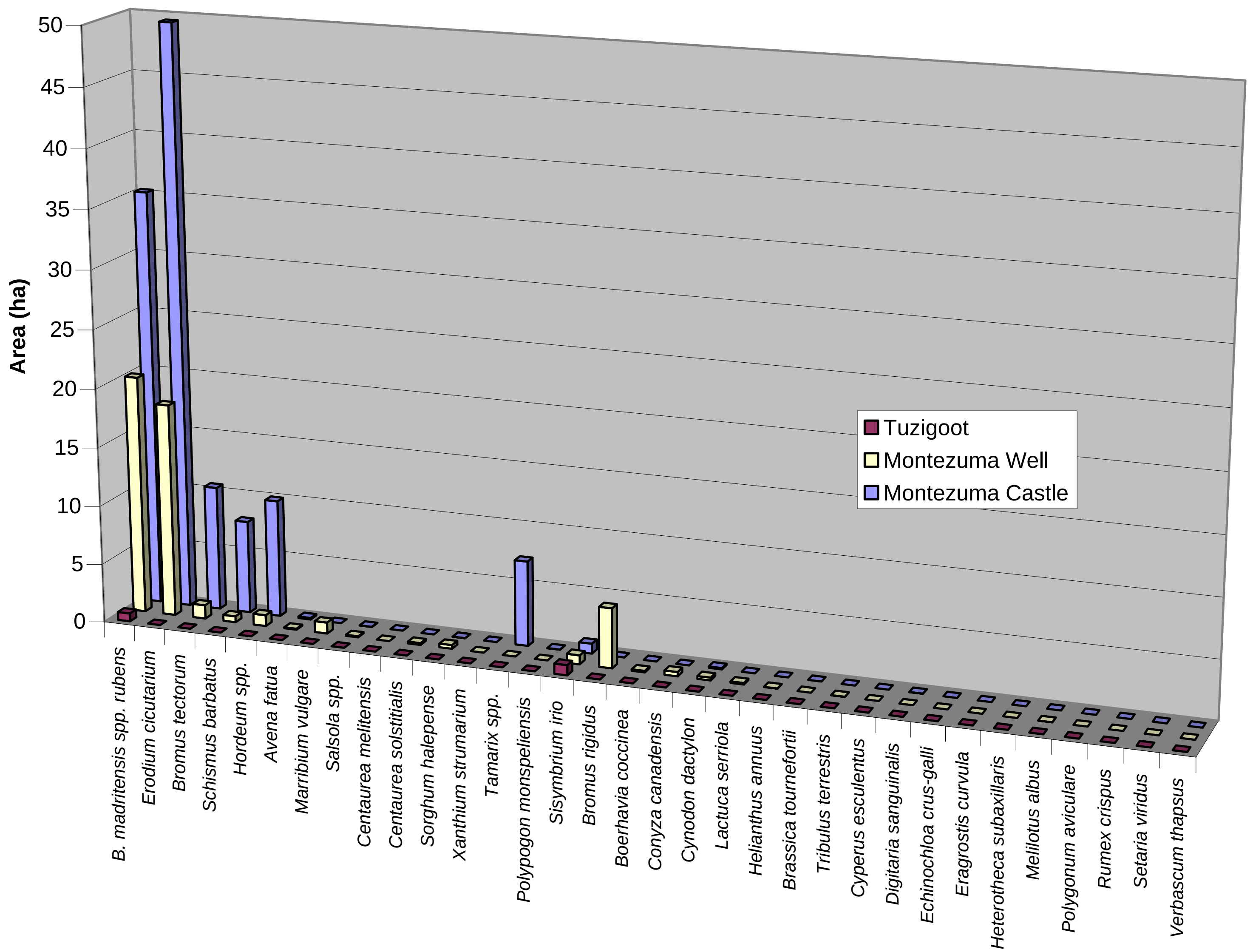
T denotes area < .01 ha.
- denotes species not observed.

Figure 4 depicts species which are widely distributed, but gives no indication of the level of infestation. In contrast, Figure 5 displays actual land area occupied by target species. Figure 5 highlights *Erodium cicutarium* and *B. matritensis ssp. rubens* as the most dominant species across the three park units. These species are the two most widely dispersed (Figure 4) as well as the most ubiquitous, infesting over 50 hectares each across the three park units. According to Figure 5, *Bromus tectorum*, *Hordeum spp.* and *Schismus barbatus*, also infest sizeable land areas (<10 ha total), primarily in MCCU; these four target plants are also widely distributed (Figure 4).

In addition to recognizing species that are widely distributed across the park units, it is important to recognize target plants that are occurring in small but concentrated patches. These species may have the potential to become more widely dispersed across the study area in the future. The densest patches for these species appear in Table 4.

Species	Park Unit	Area Occupied (ha)	Percent Cover
Conyza canadensis	MCWU	2.226	5-25%
Cynodon dactylon	MCCU	0.087	50-75%
Cynodon dactylon	MCWU	0.551	50-75%
Hordeum spp.	MCWU	1.641	5-25%
Marribium vulgare	MCWU	4.811	5-25%
Sorghum halepense	MCWU	0.740	50-75%
Tamarix spp.	MCCU	0.069	5-25%

Figure 5. Area Infested by Nonnative Species
calculated from roaming surveys



3.2 Circular Plots/Beyond NAWMA Sampling

Of the 50 target species, seventeen species were recorded within the circular plots, ten in MCCU, 13 in MCWU, and five in TNM (Table 4). Three 1 m^2 quadrats were located within each circular plot, in which percent cover of all species were recorded to the nearest 1%. Using these data, the relative abundance of the target species was calculated (Table 4).

Table 4. Target species occurrences and relative abundances within circular plots.

Species	MCCU Occurrences	MCCU Foliar cover	MCWU Occurrences	MCWU Foliar cover	TNM Occurrences	TNM Foliar cover
Avena fatua	-	-	1	0.03%	-	-
Boerhavia coccinea	-	-	2	0.11%	-	-
Brassica tournefortii	-	-	-	-	-	-
Bromus rigidus	6	2.78%	3	2.72%	-	-
Bromus rubens	20	8.78%	21	5.39%	48	4.02%
Bromus tectorum	12	2.50%	1	0.03%	-	-
Centaurea melitensis	-	-	1	0.03%	-	-
Centaurea solstitialis	-	-	-	-	-	-
Conyza canadensis	-	-	-	-	-	-
Cynodon dactylon	-	-	1	0.69%	-	-
Cyperus esculentus	-	-	-	-	-	-
Digitaria sanguinalis	-	-	-	-	-	-
Echinochloa crus-galli	-	-	-	-	-	-
Eragrostis curvula	-	-	-	-	-	-
Erodium cicutarium	3	0.08%	8	3.61%	67	1.30%
Helianthus annuus	-	-	-	-	-	-
Heterotheca subaxillaris	-	-	-	-	-	-
Hordeum spp.	4	1.31%	-	-	-	-
Lactuca serriola	-	-	-	-	-	-
Marrubium vulgare	-	-	1	0.28%	1	0.01%
Melilotus albus	-	-	-	-	-	-
Polygonum aviculare	-	-	1	T	5	T
Polypogon monspeliensis	1	T	-	-	-	-
Rumex crispus	1	0.03%	-	-	-	-
Salsola spp.	-	-	1	0.03%	-	-
Schismus barbatus	7	0.56%	5	0.14%	-	-
Setaria viridus	-	-	-	-	-	-
Sisymbrium irio	3	0.61%	4	0.11%	23	0.77%
Sorghum halepense	1	0.03%	-	-	-	-
Tamarix spp.	-	-	-	-	-	-
Tribulus terrestris	-	-	-	-	-	-
Verbascum thapsus	-	-	-	-	-	-
Xanthium strumarium	-	-	-	-	-	-

T denotes relative abundance < .01%.
- denotes species not observed.

4. Discussion

To our knowledge, this project represents the first time roaming surveys for nonnative species mapping has been implemented in Arizona. As a result, this effort served as a test of the method as well as a data-collection exercise. Some adjustments were made as data collection proceeded. For example, the number of circular plots collected for MCCU and MCWU were drastically reduced (from 100 to 19 per park unit). In addition, we believe several species to be underestimated due to the time of year of the surveys. By July, several of the annual species were already dormant or dead, making them difficult to identify. However, this method has yielded detailed maps of the location, distribution, and abundance of the most problematic plants within Arizona national parks, which will enhance decisions made by land managers. In addition, the data collected will serve as a baseline for long-term monitoring, allowing for evaluation in changes of weed populations over time.

4.1 Comparison of Methods:

The circular plots were implemented to estimate spatial bias and accuracy of the roaming surveys. Stohlgren et al. (no date) suggest randomly locating these plots and comparing the foliar cover of target species within to the foliar cover of target species collected during the roaming surveys. This comparison identifies observer bias to particular regions of the study area (i.e., near roads or riparian areas).

As a whole, the circular plots detected less target species and lower abundances of target species (Table 5). For MCCU and MCWU, the circular plots added one target species each. The circular plot method added two target species for TNM.

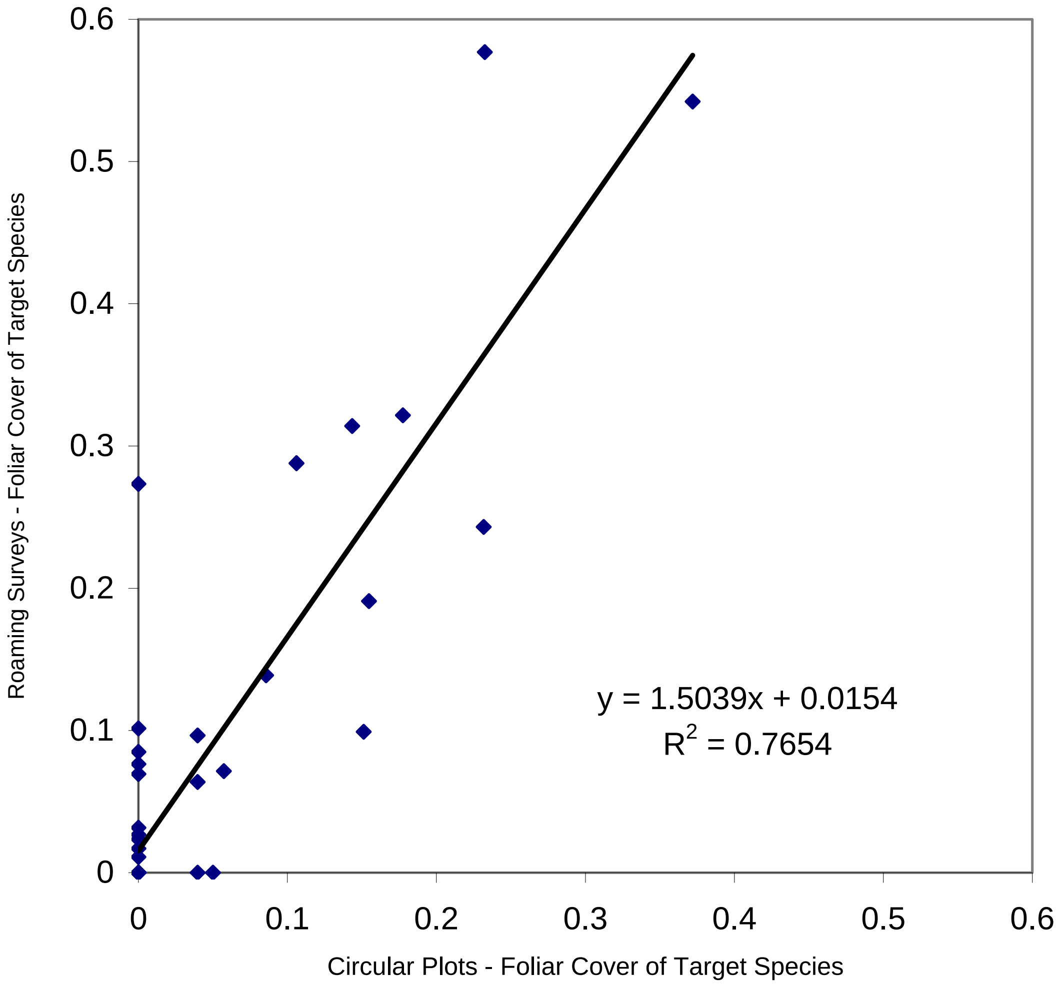
Table 5. Target species detected by roaming surveys and circular plots.

Method	MCCU	MCWU	TNM
Roaming surveys	26	32	3
Circular plots	10	13	5
Species in common	9	12	3

The stark difference in target species detected by the two methods suggests that MCCU and MCWU were not sufficiently sampled using the circular plot method. Per unit area, TNM received many more circular plots (1 plot/0.9 ha, compared to 1 plot/19.3 ha for MCCU and 1 plot/8.6 ha for MCWU). However, Stohlgren et al. (no date) suggest allocating only ten percent of field resources to the supplemental circular plot method. Nineteen circular plots for TNM were sampled in two and one-half days and roaming surveys for TNM were completed in three days, allocating 45% of field resources to sufficient circular plots. Based on these numbers, circular plots were drastically reduced for the remaining two park units. As a result, fewer species were detected by circular plots within the ten-percent of resources rule.

Figure 6 depicts foliar cover of target species collected via circular plots plotted against foliar cover of target species collected via roaming surveys. Both datasets were transformed using a cube-root transformation. The relative abundance of target species is rather consistent between the methods ($R^2 = 0.77$), indicating that roaming surveys perform well at estimating abundance of target species. Roaming surveys rather consistently estimated percent cover higher than circular plots. This may be due to the cover classes used in roaming surveys. Percent cover of target species were estimated to the nearest 1% during circular plots; circular plot data may more accurately reflect species abundance.

Figure 6. Relative abundance of target species collected via roaming surveys and circular plots.



The goals of this project were 1) to map the spatial location, distribution and abundance of 50 nonnative plants in Montezuma Castle and Tuzigoot National Monuments; and 2) to test the efficacy of roaming surveys for nonnative plant mapping using a modified version of the "Beyond NAWMA" (Stohlgren et al. no date) weed mapping standards suggested by the North American Weed Management Association (NAWMA) in these National Parks. The maps produced in this report reflect approximately 400 hours of fieldwork and 60 hours of work in the office. Based on the accuracy assessment performed and the effort expended to yield these products, we feel roaming surveys are a cost-effective method for producing maps of nonnative species for these three national monuments.

The circular plot method described by Stohlgren et al. (no date) for assessing the roaming surveys performed well in this study, but seem to require much more than the 10% of resources specified in these guidelines. The small sample sizes of circular plots employed for MCCU and MCWU performed much worse than roaming surveys for detecting target species, however, foliar cover for detected species was rather consistent among the methods. The circular plot method appears to be most useful in assessing consistency in estimating foliar cover across the two methods.

5. Recommendations

Our overall recommendation is to pursue roaming surveys in conjunction with a small number of circular plots for mapping location, distribution, and abundance of nonnative species in Sonoran Desert Network parks. Roaming surveys appear to perform well for capturing plant species distribution and abundance, at least for small parks (less than 500 ha). Circular plots collected using approximately ten percent of field resources allow for roaming survey accuracy assessment. We also suggest the following activities to augment the data collected in this study:

1) Sample earlier in the growing season. Numerous dead target species individuals were observed, suggesting that sampling may have missed the peak in abundance of the target species. Some target species may have been missed altogether.

2) Implement an analytical prioritization technique such as Hiebert and Stubbendieck (1993) for management planning. This system uses species location, distribution, and abundance information in conjunction with phonological information to determine which nonnative species should receive first priority for control measures. The data collected through this study would feed directly into such a system, and would enhance efforts toward an exotic plant management plan for Montezuma Castle and Tuzigoot National Monuments.

Further testing of these methods in additional parks of varying size will add information regarding the efficacy and cost-effectiveness of roaming surveys for nonnative plant mapping.

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Appendix A

Sample circular plot field data collection sheet

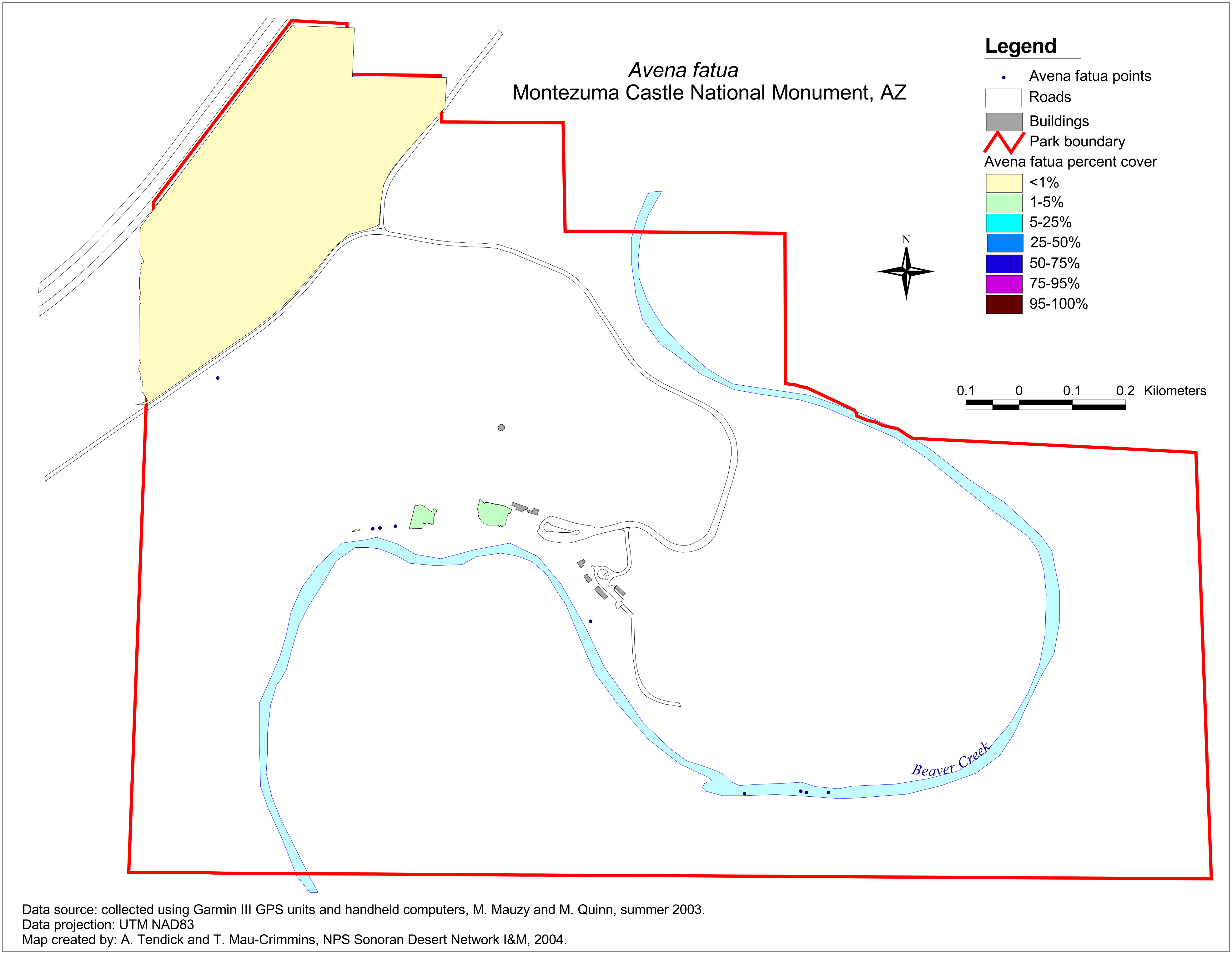
Sample data sheet

	Q = QUAD
Botanist:	SS = SUBPLOT SEARCH (1 for presence)
Date:	TRAMPLING: 1 undisturbed, 2 moderate, 3 heavy
UTM:	.01 indicates less than 1 percent cover
Plot Number	1 indicates species presence in the subplot search column
Location:	All cover estimates are to the closest 1%
	N/I Native or introduced

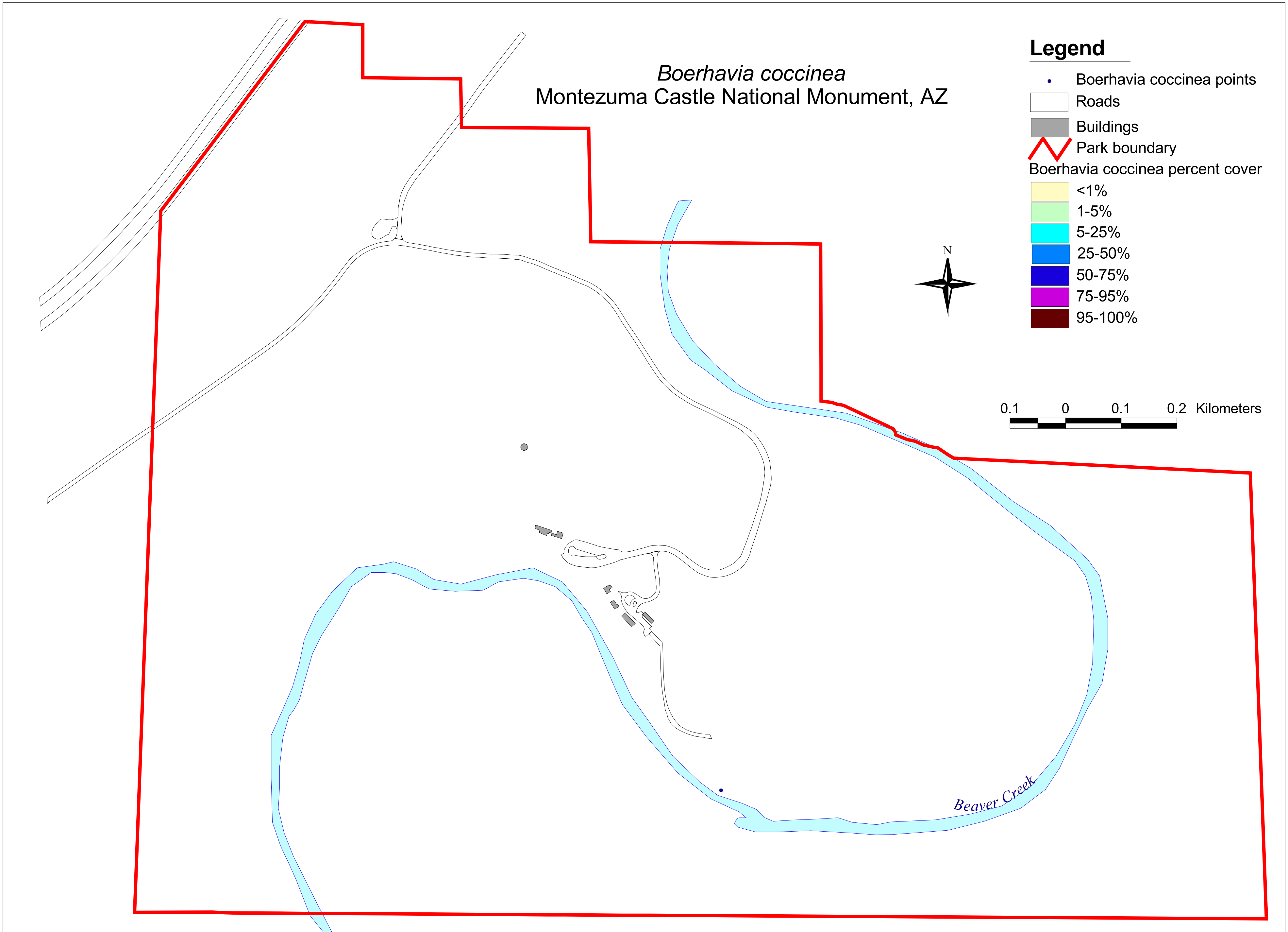
		Grnd Variables	**Q1**	**Q2**	**Q3**	
		dung				
		lichen				
		litter/duff				
		moss				
		road				
		rock				
		root/bole				
		soil				
		stream				
		trash/junk				
		water				
		wood				
		Condition Class				
		Trampling				
Comment	**N/I**	**Species**	**Q1**	**Q2**	**Q3**	**SS**

Appendix B

Target species distribution and abundance maps



Avena fatua
Montezuma Castle National Monument, AZ
Legend
Avena fatua points
Roads
Buildings
Park boundary
Avena fatua percent cover
<1%
1-5%
5-25%
25-50%
50-75%
75-95%
95-100%
N
0.1 0 0.1 0.2 Kilometers
Beaver Creek
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.



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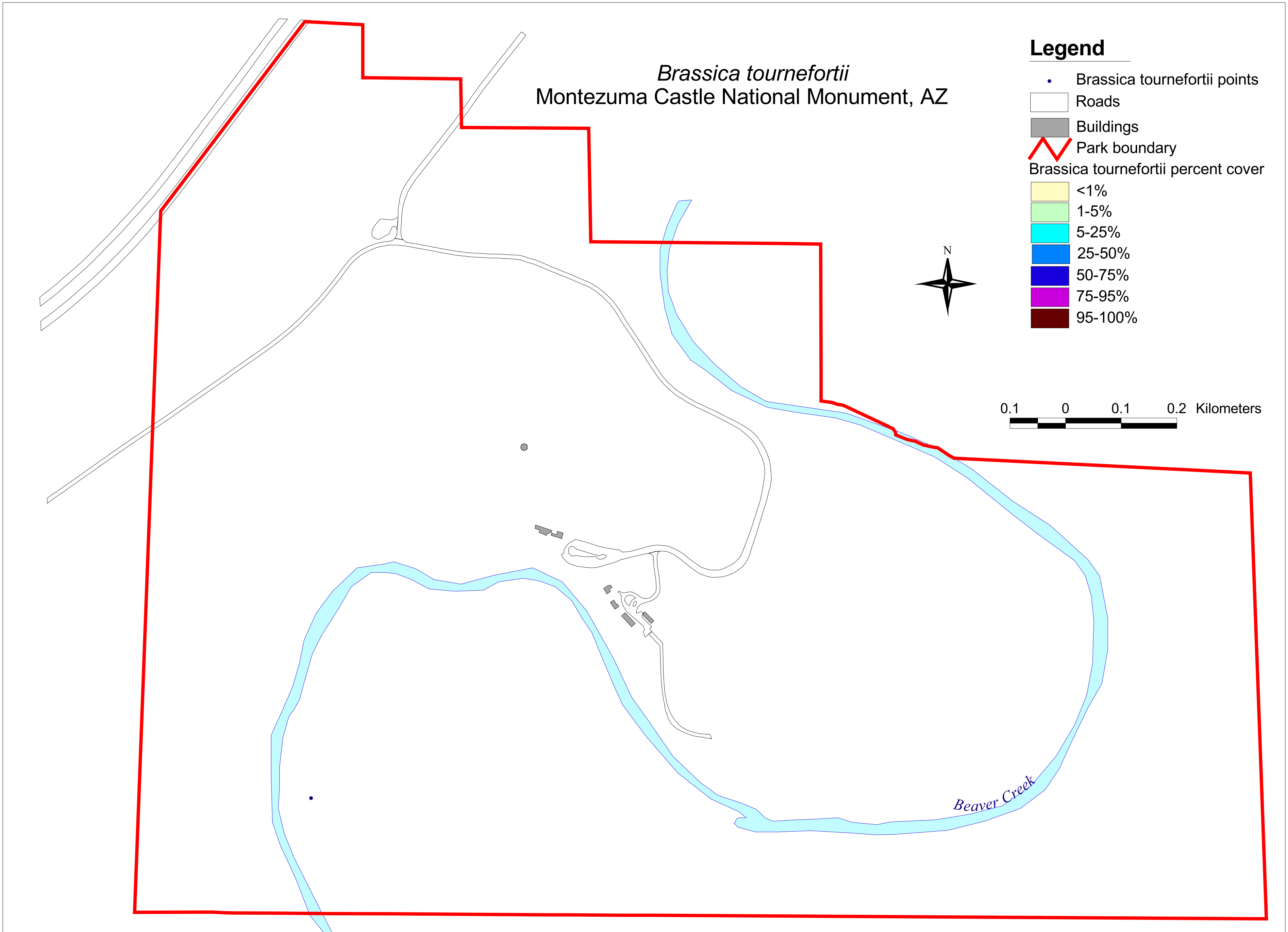

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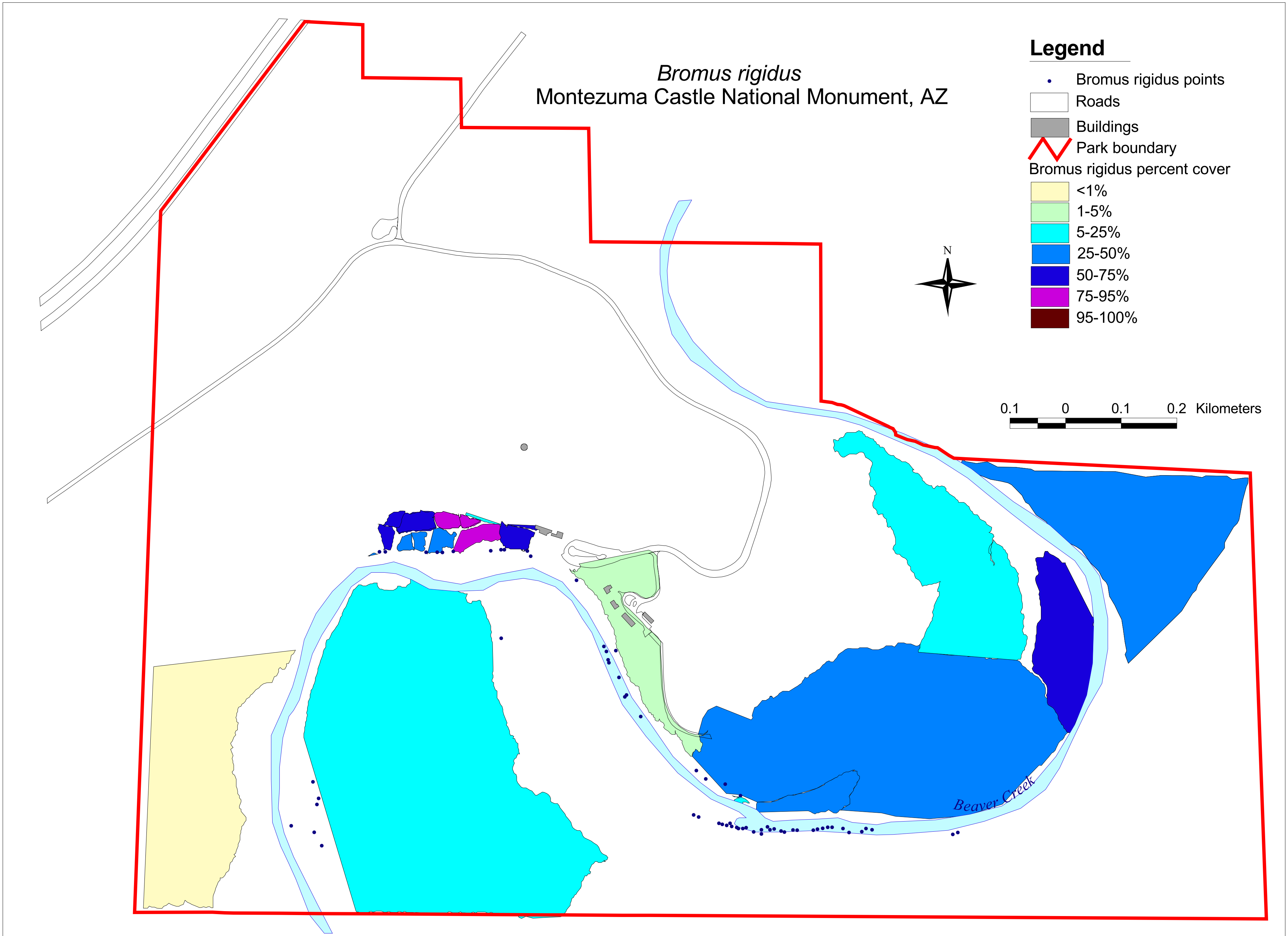

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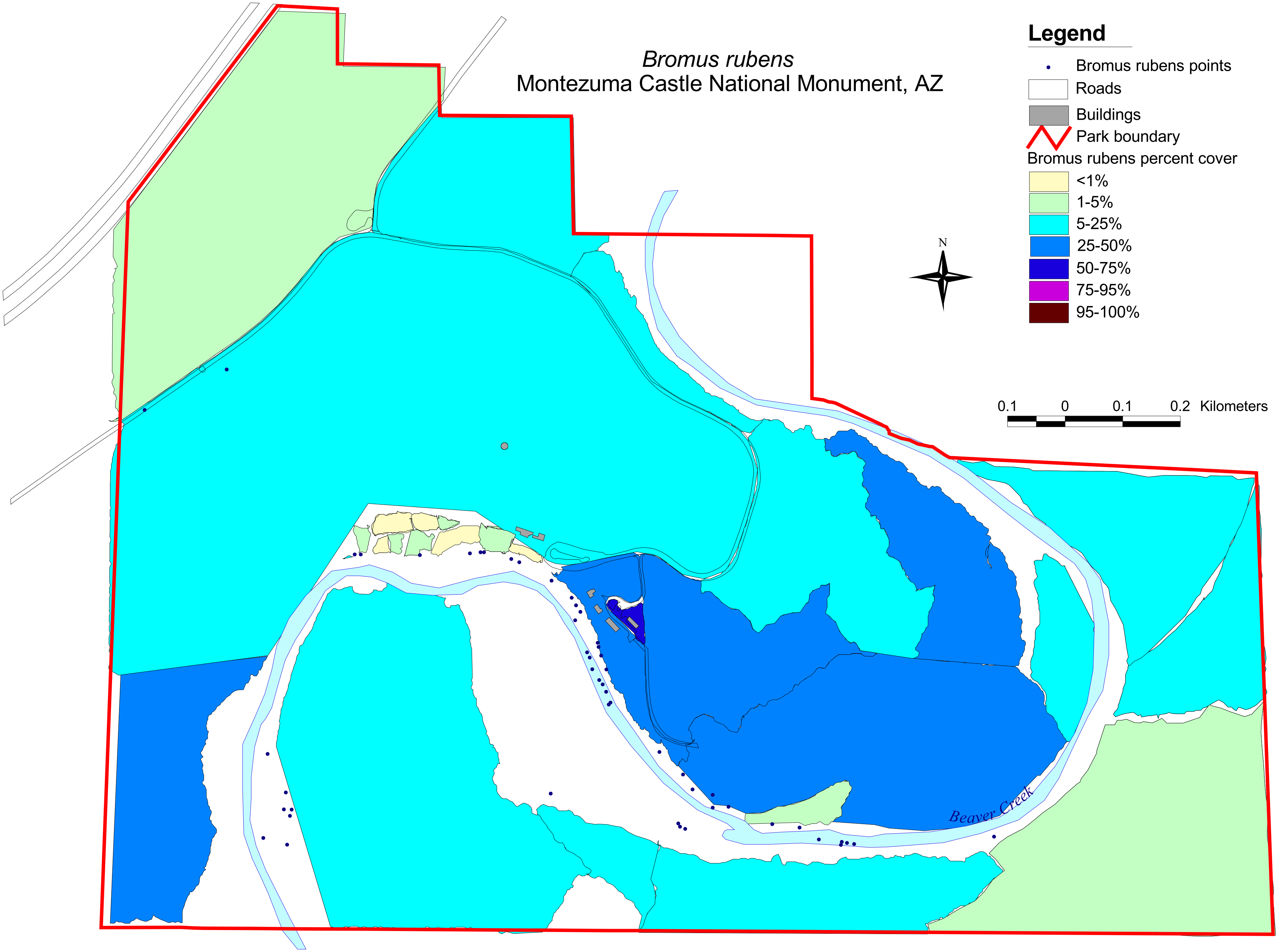

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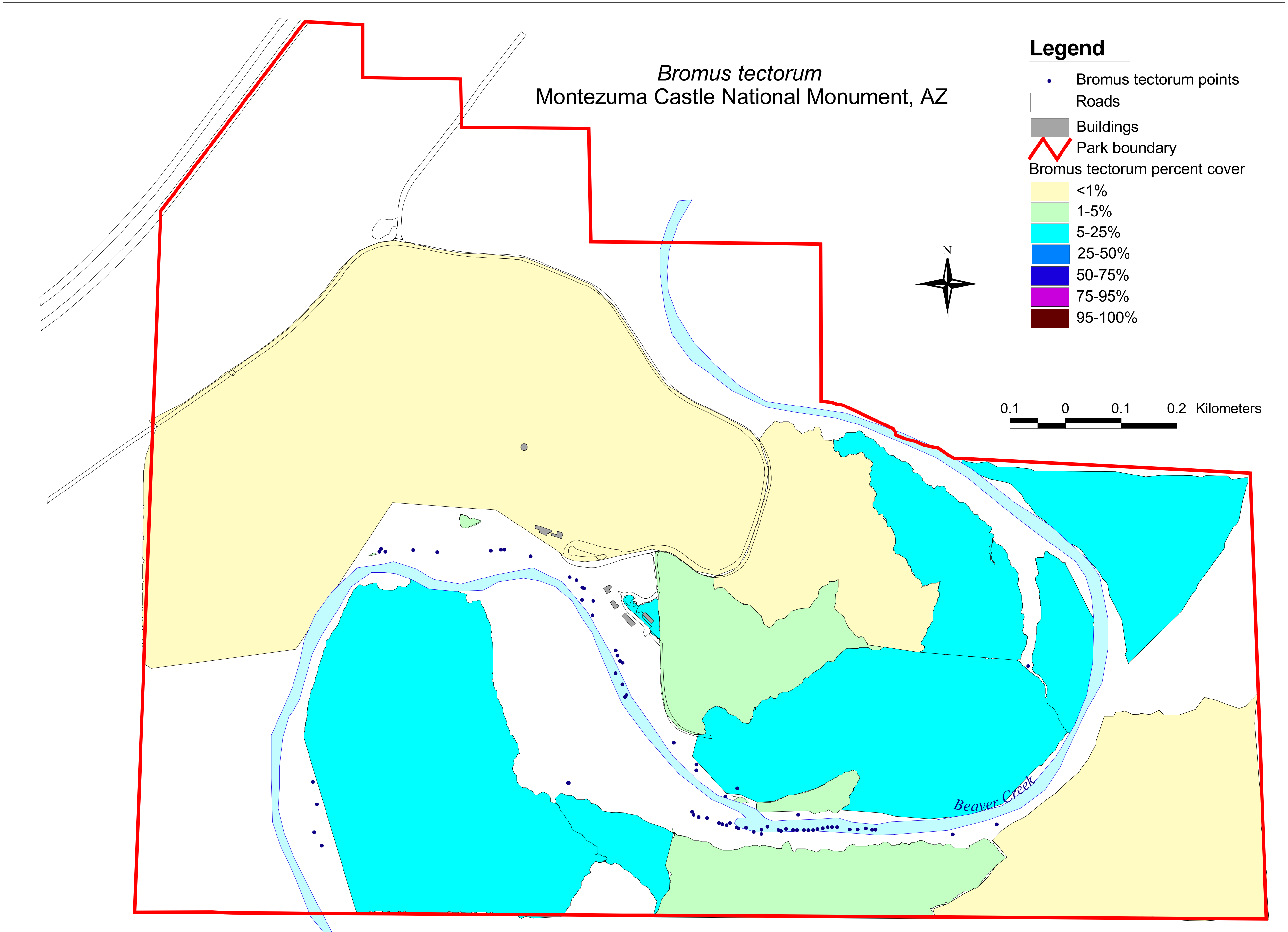

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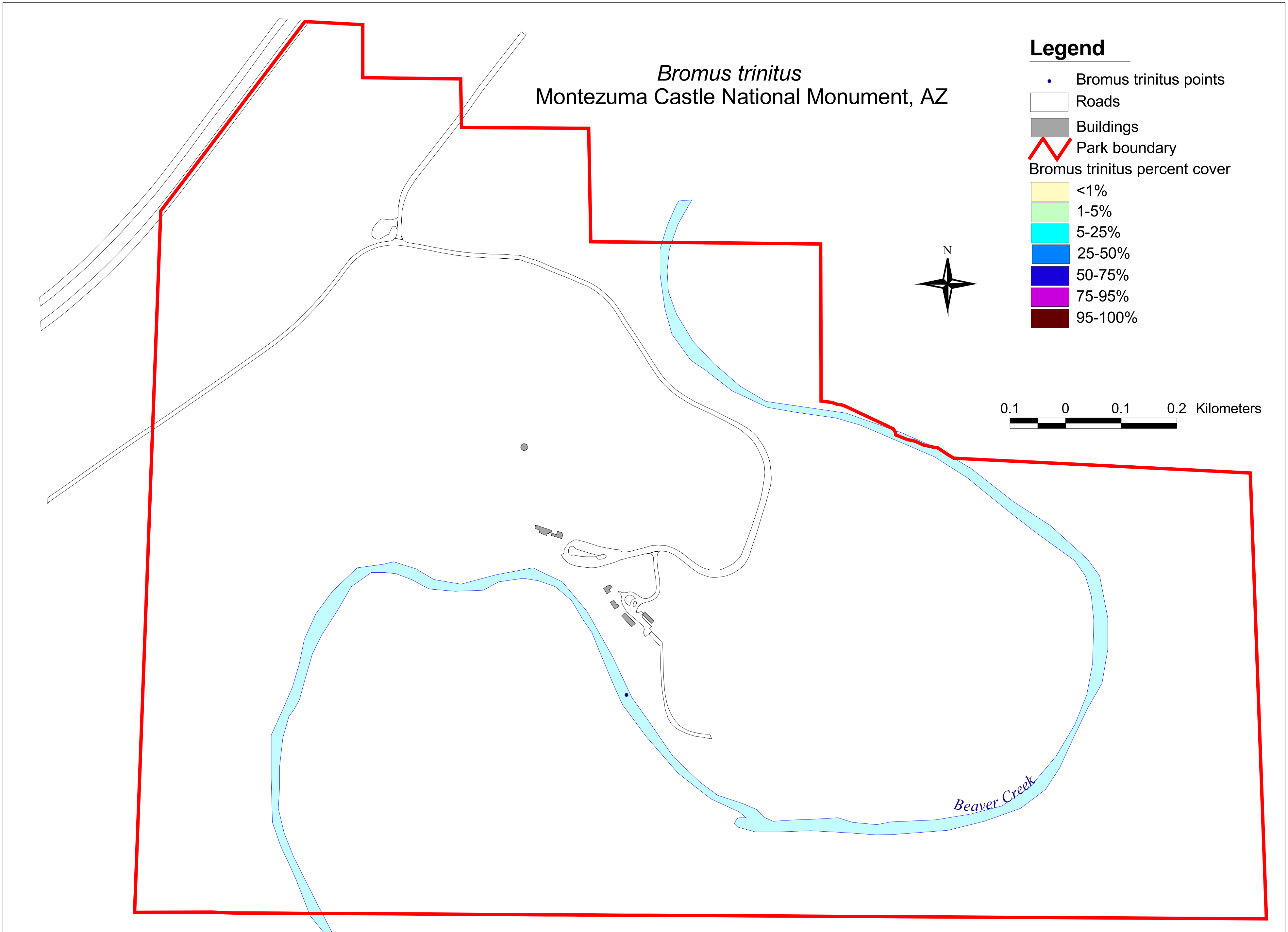

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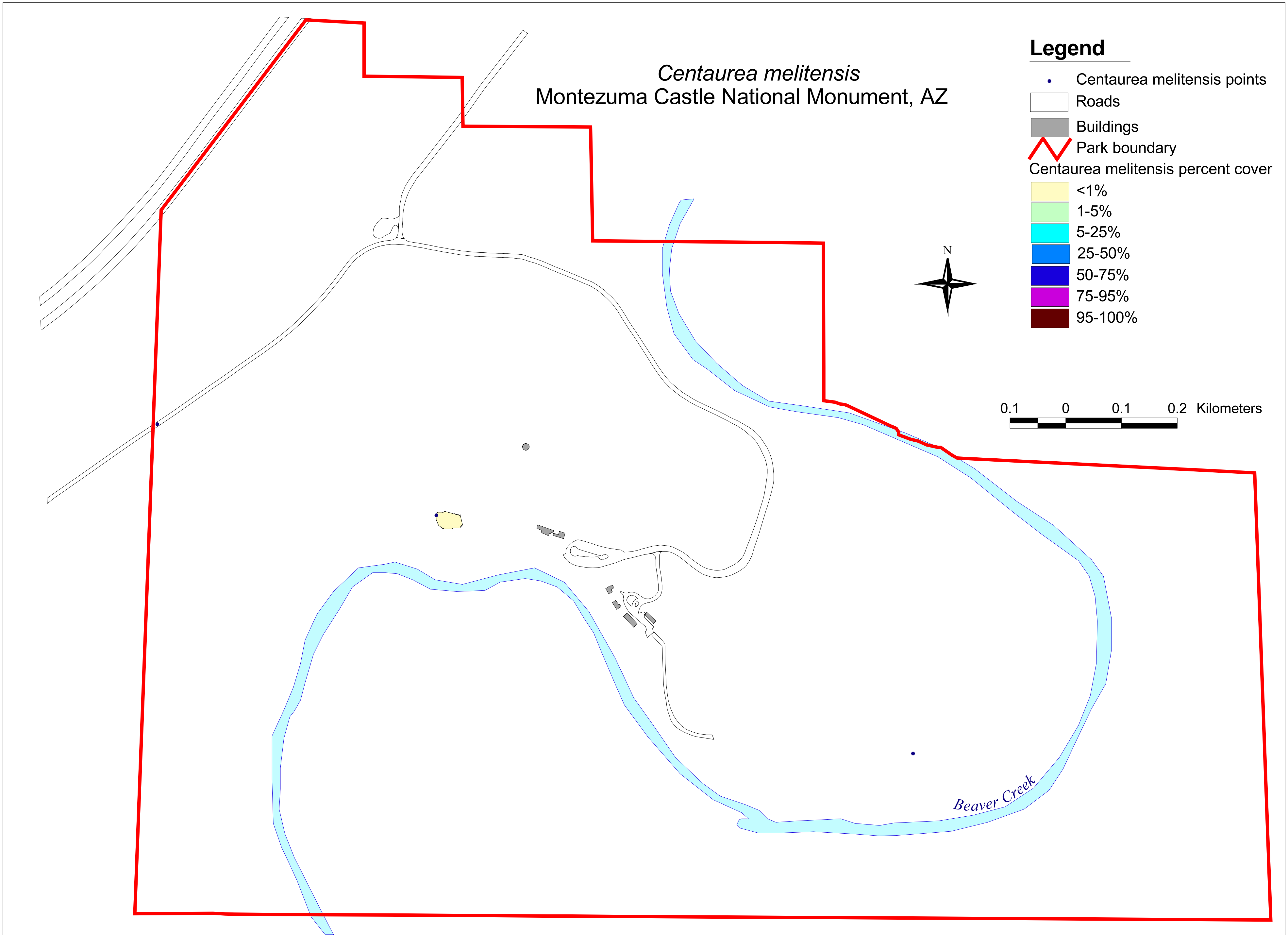

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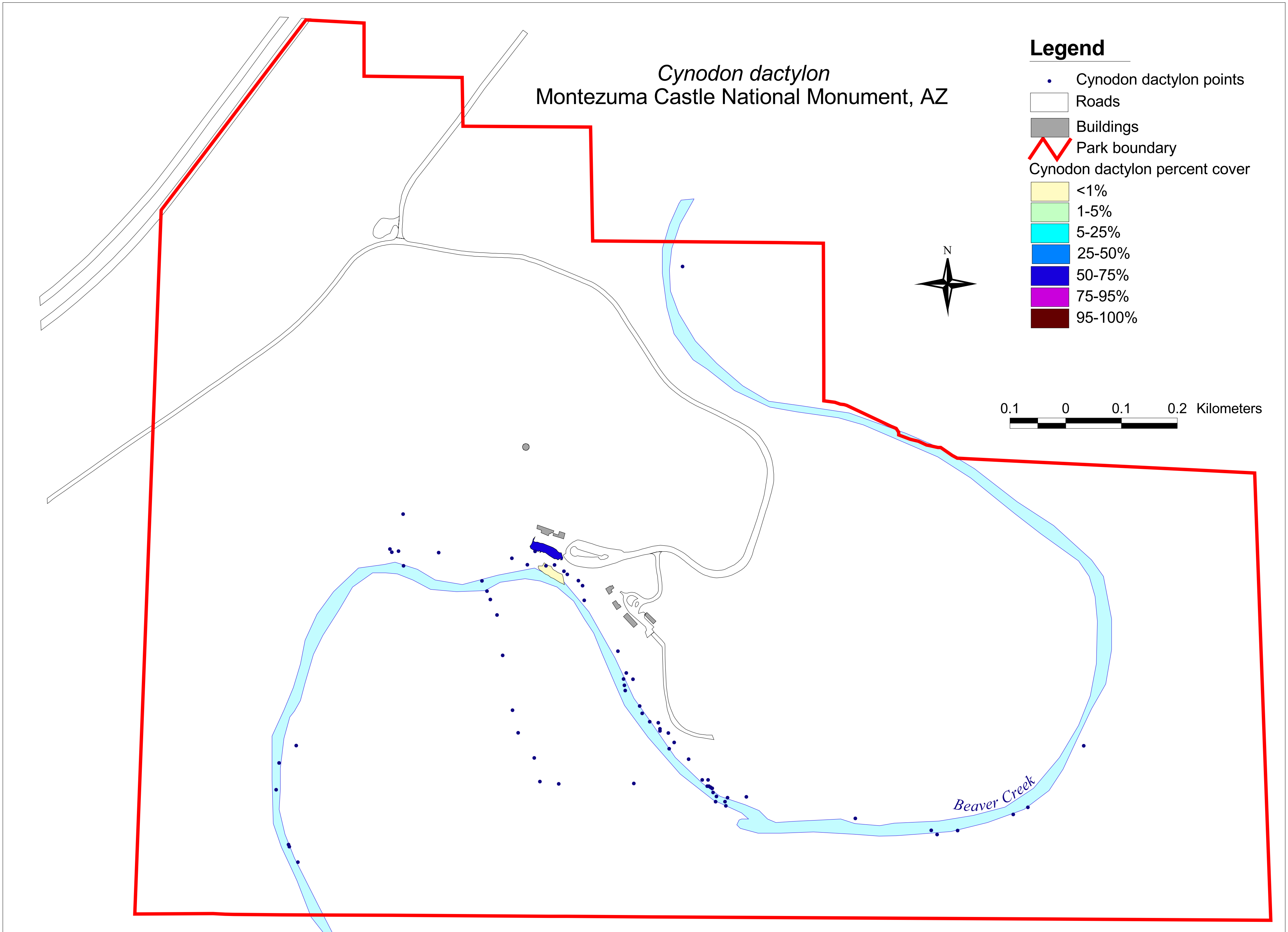

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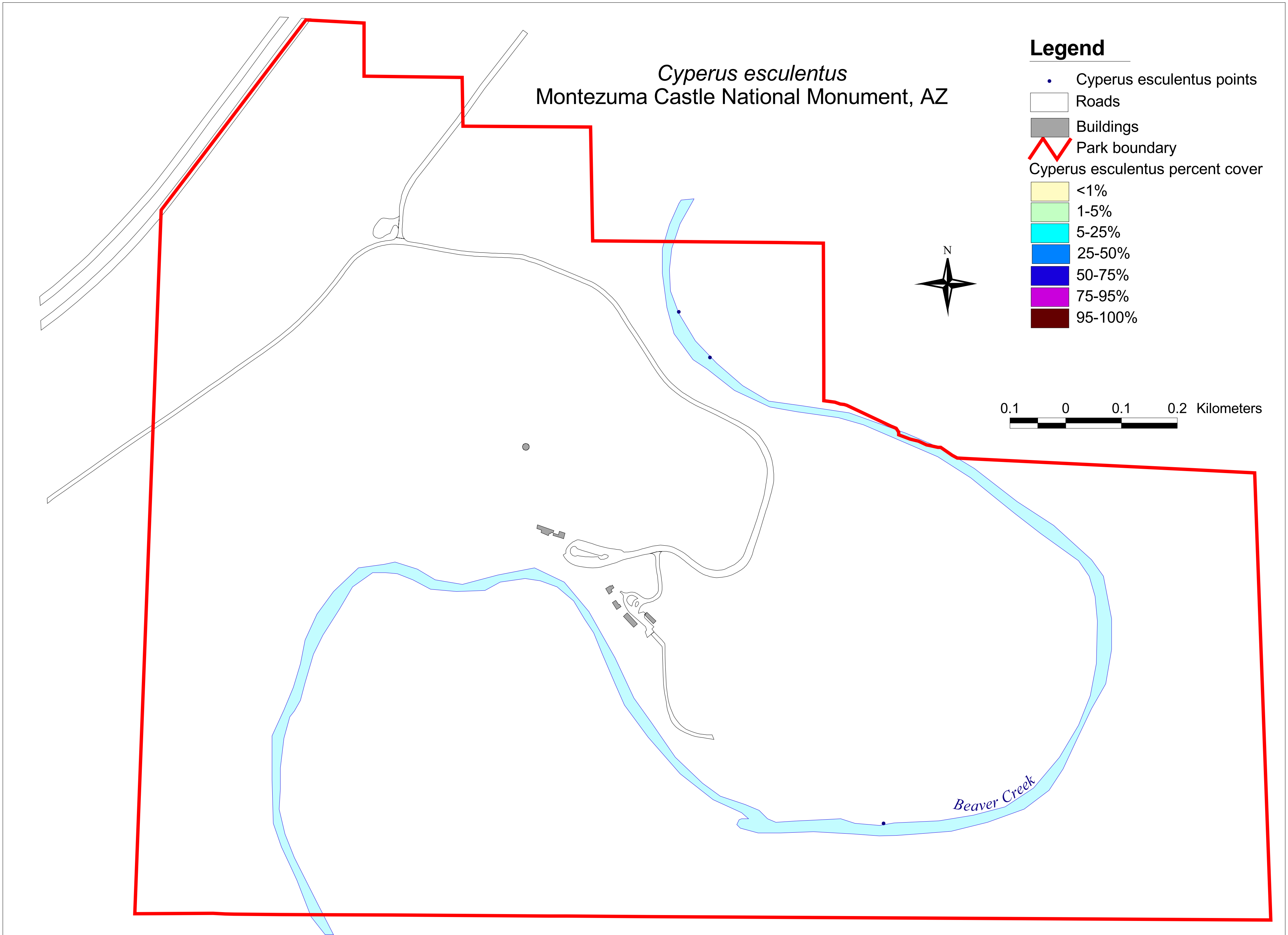

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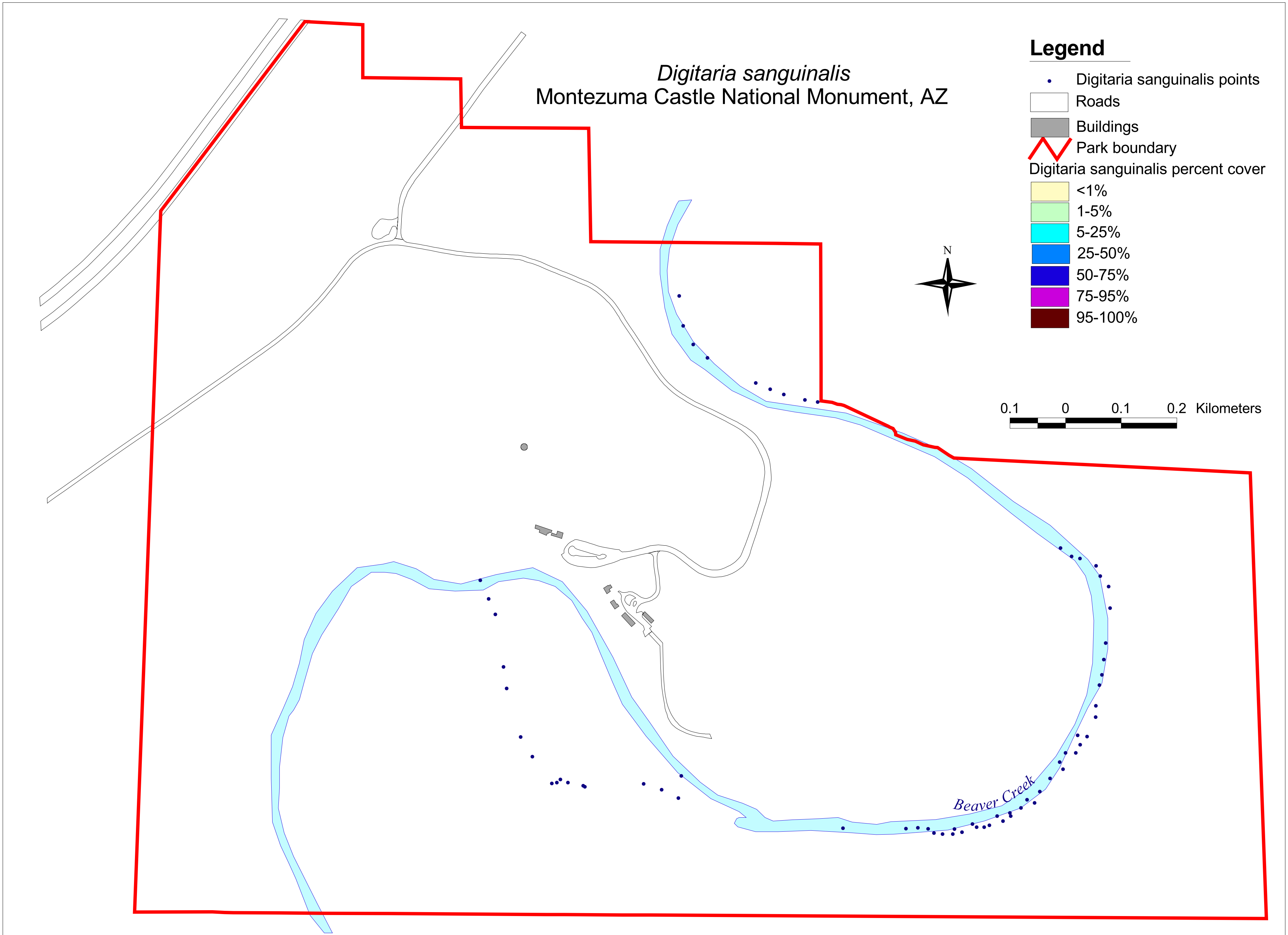

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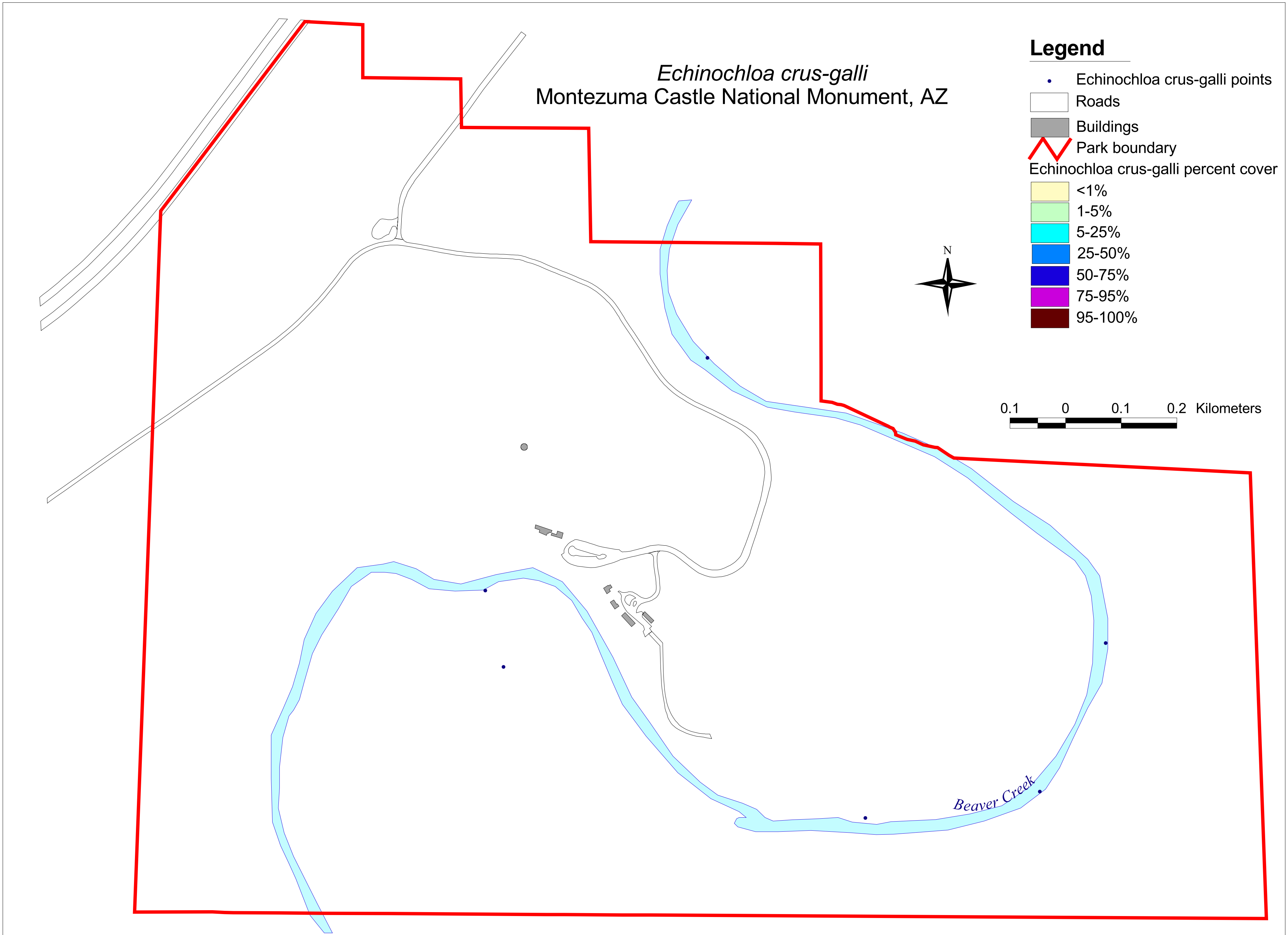

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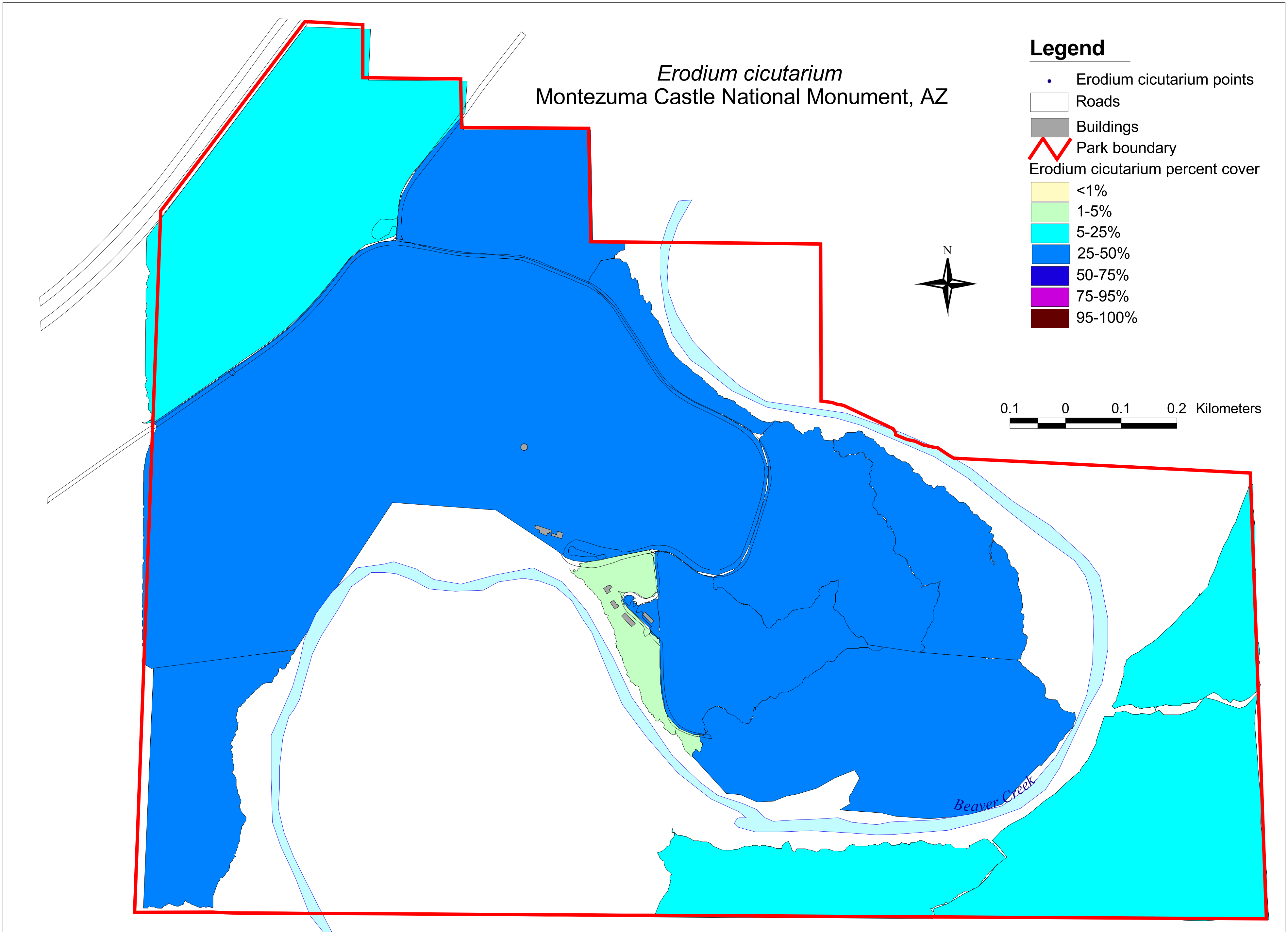

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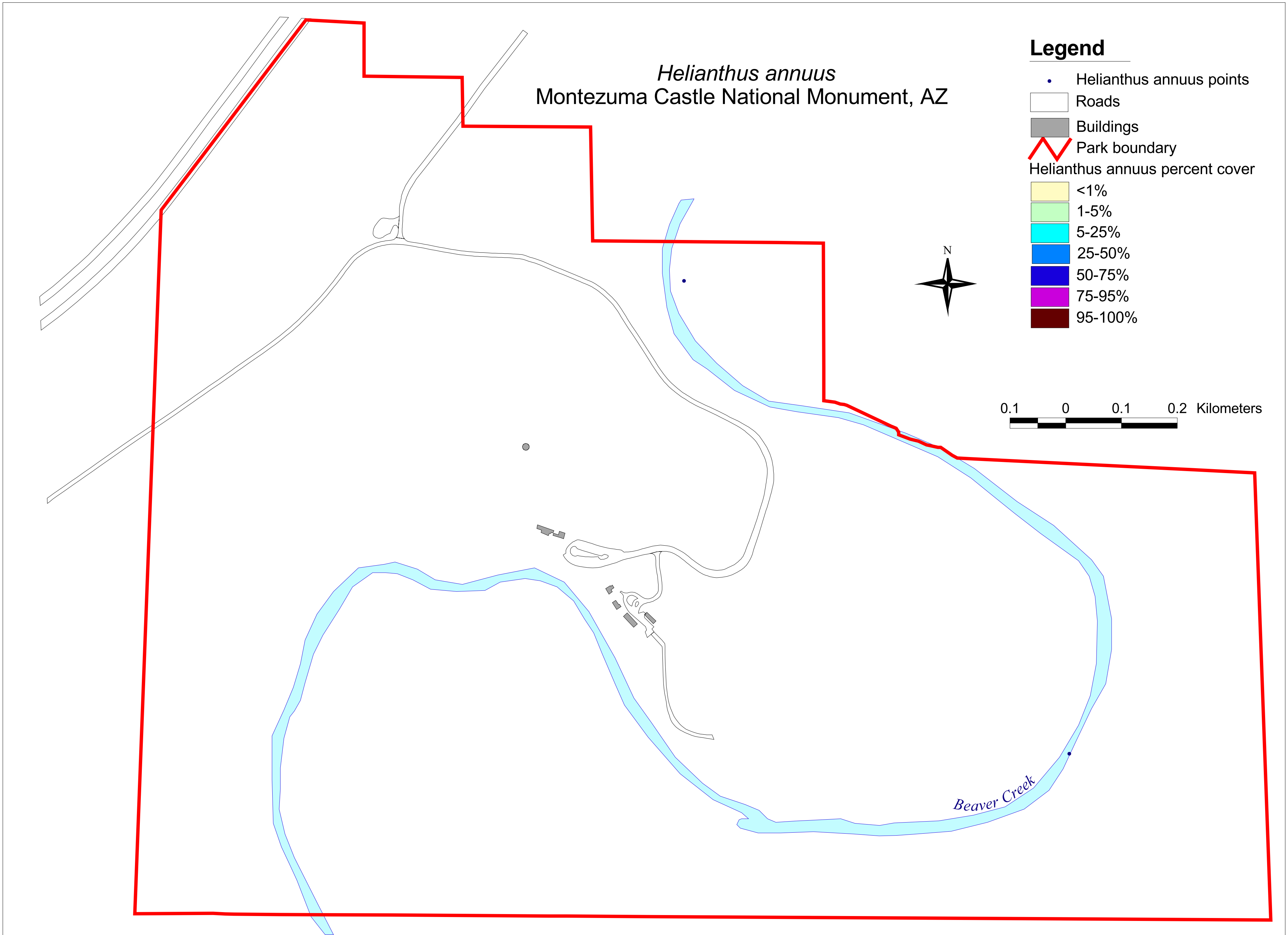

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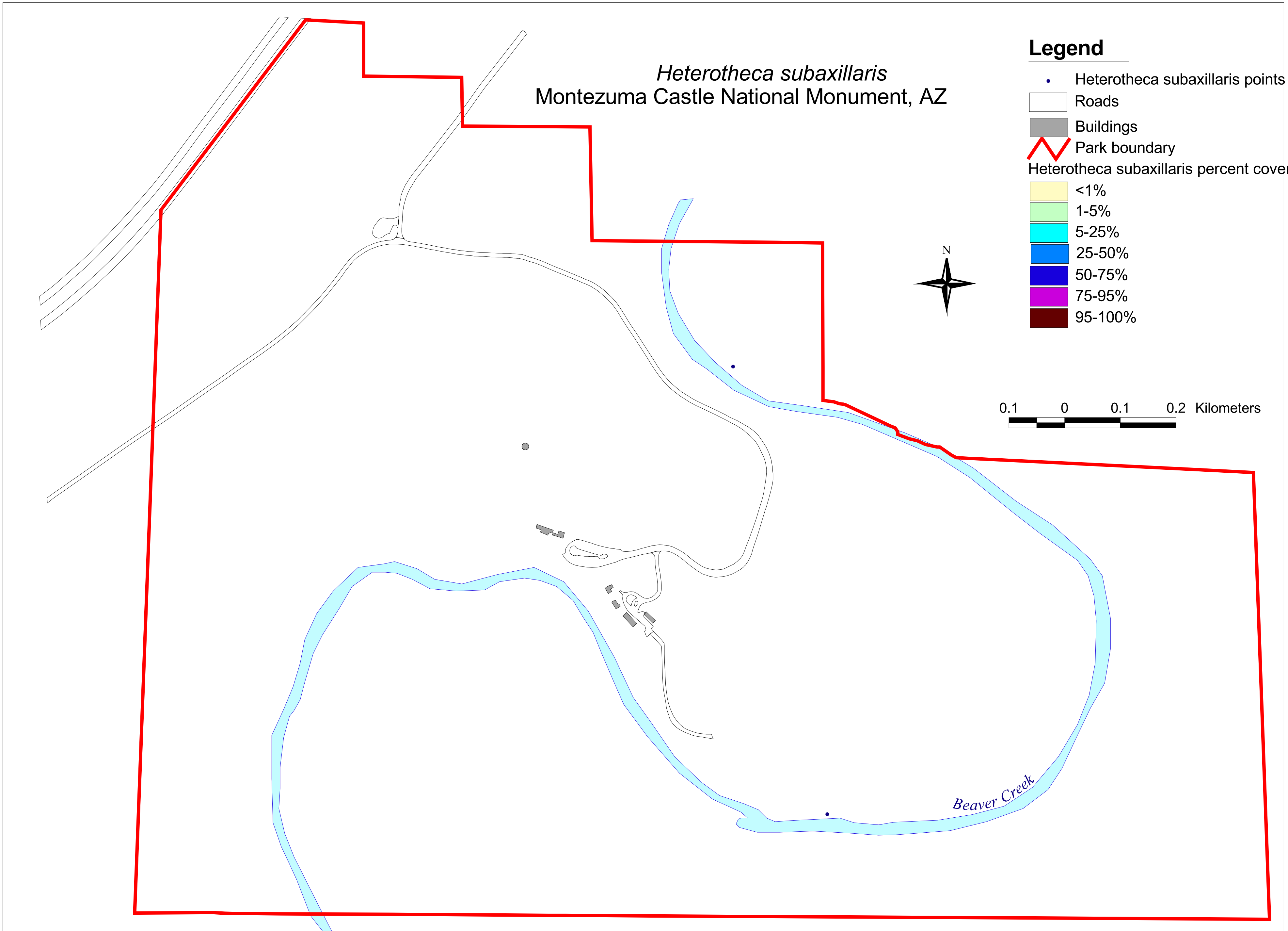

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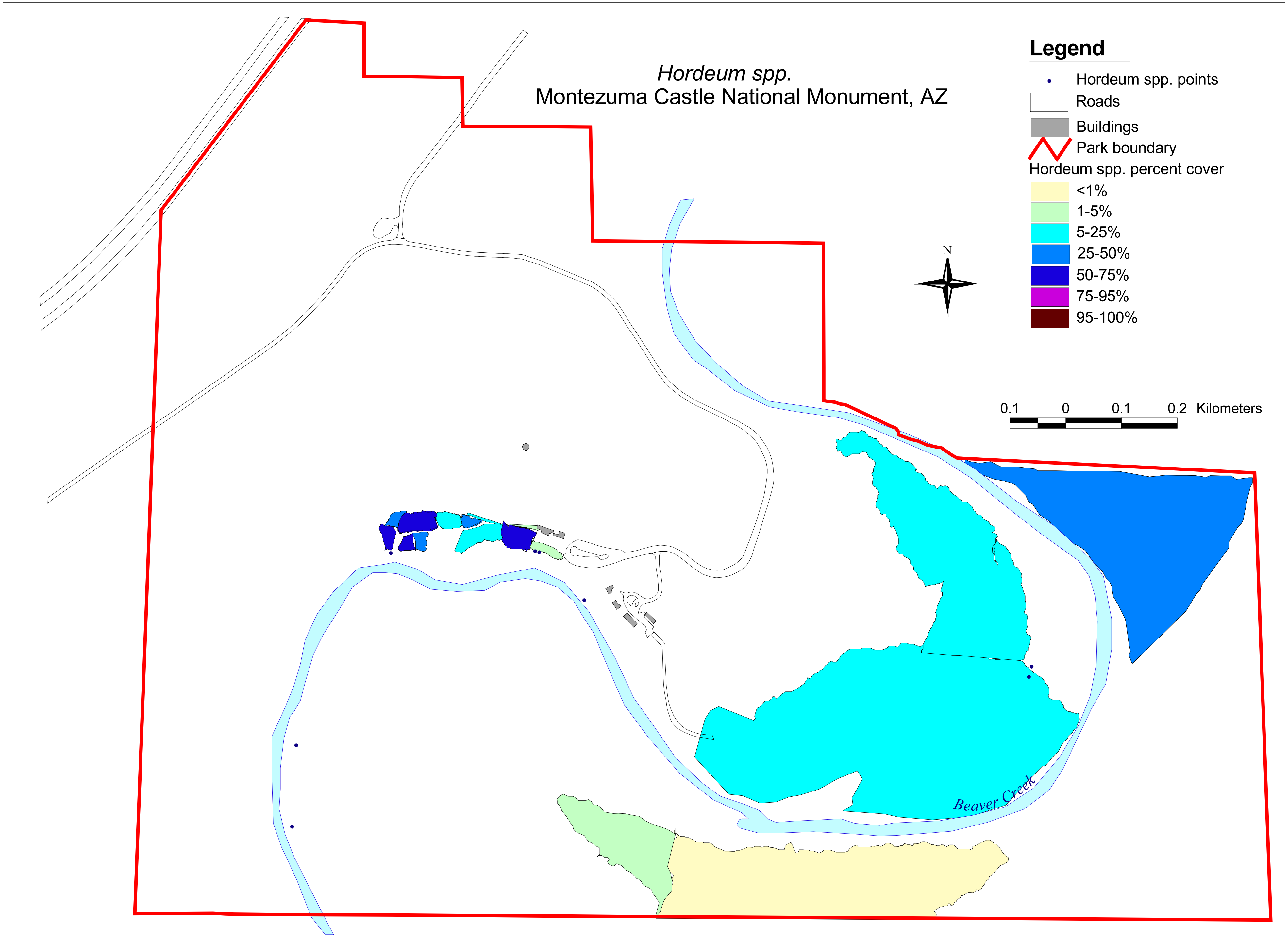

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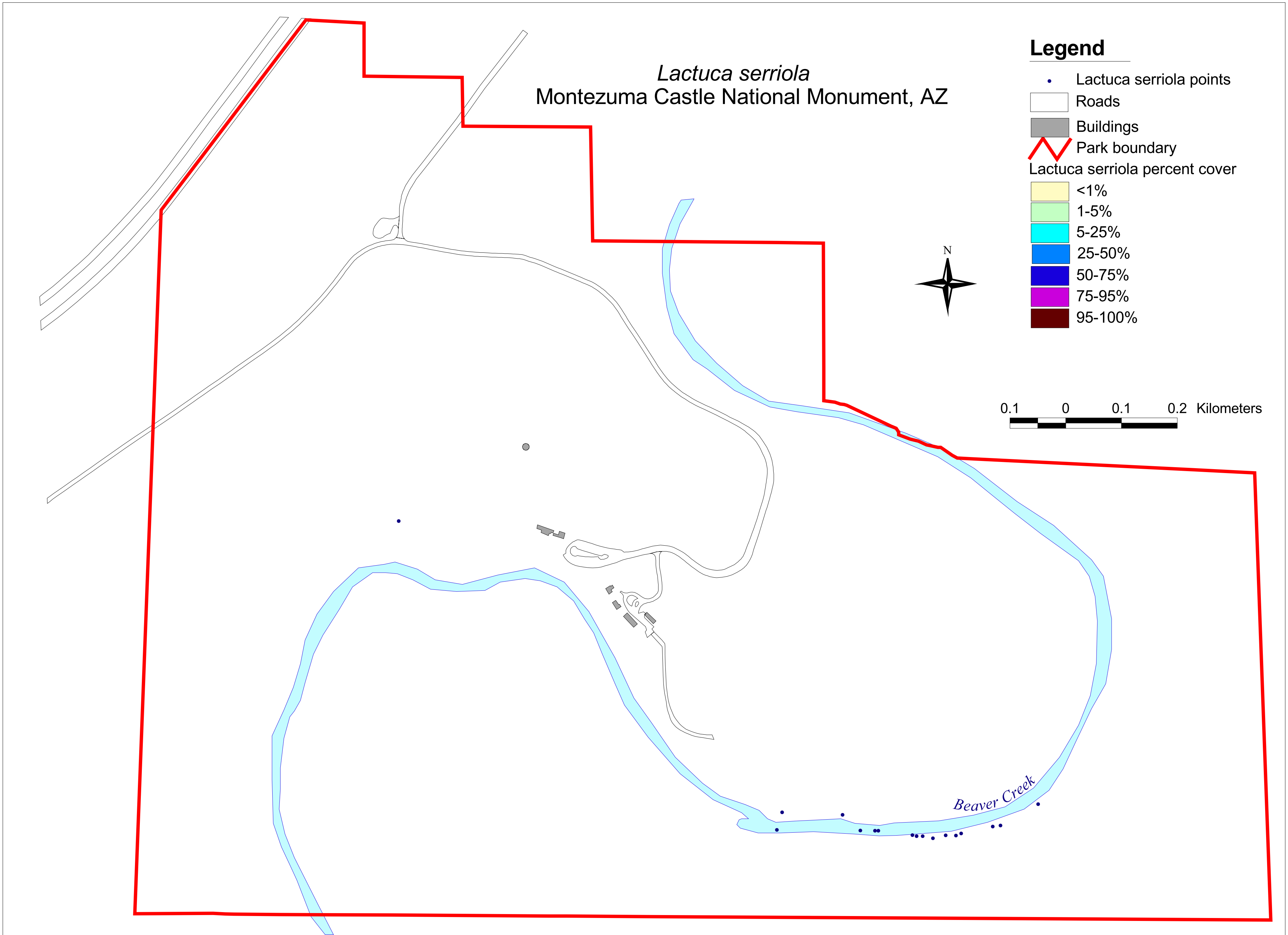

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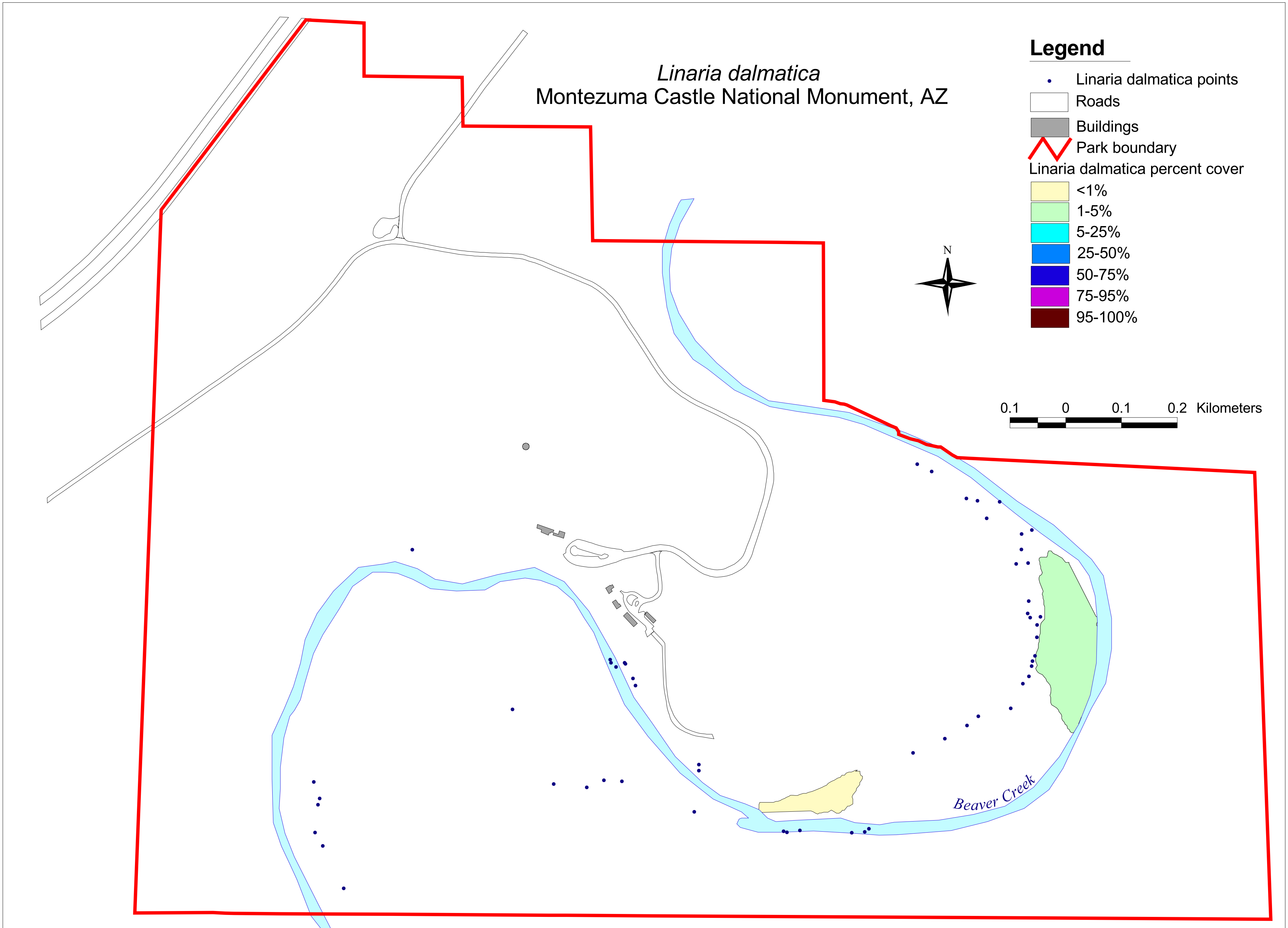

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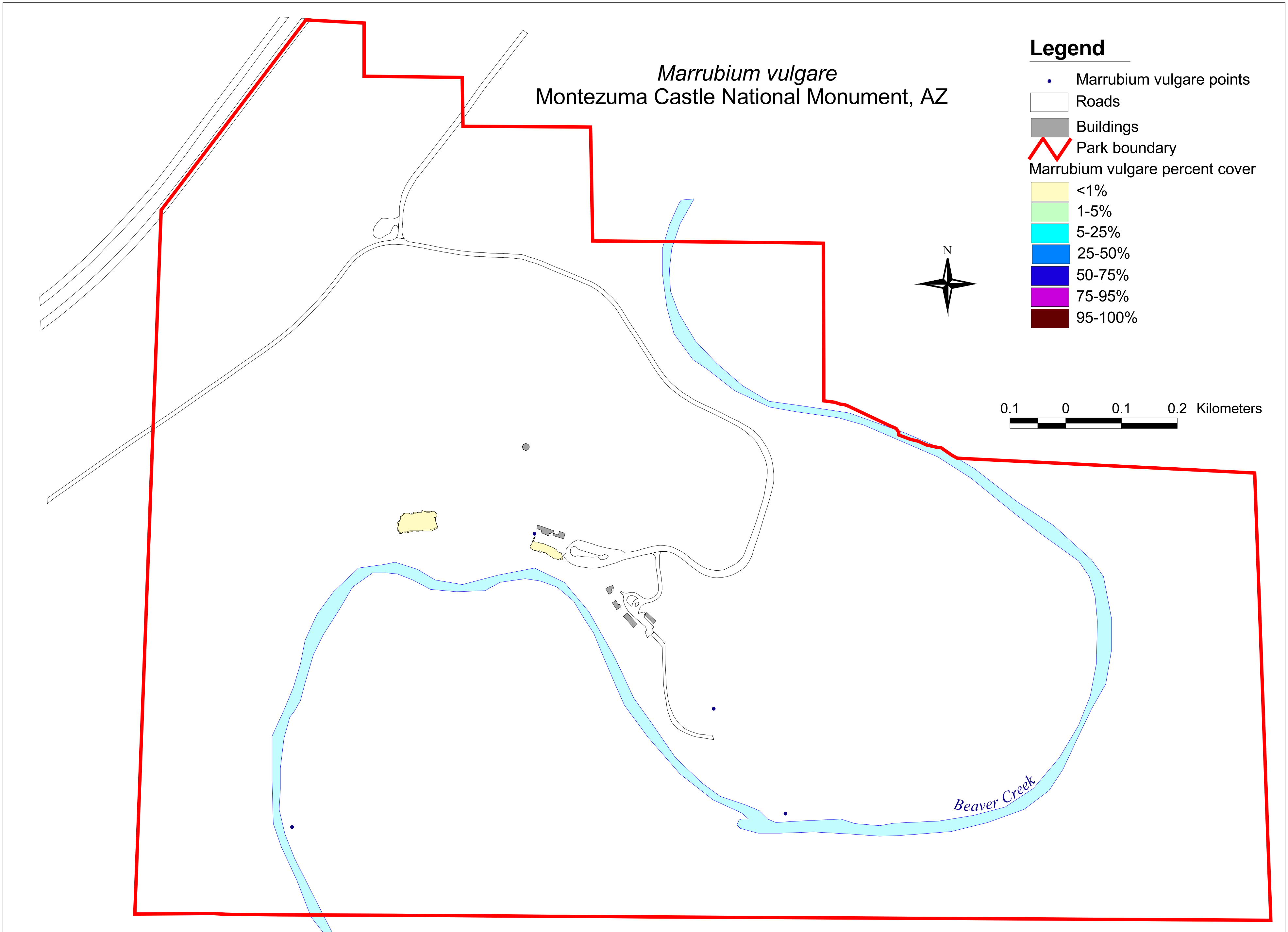

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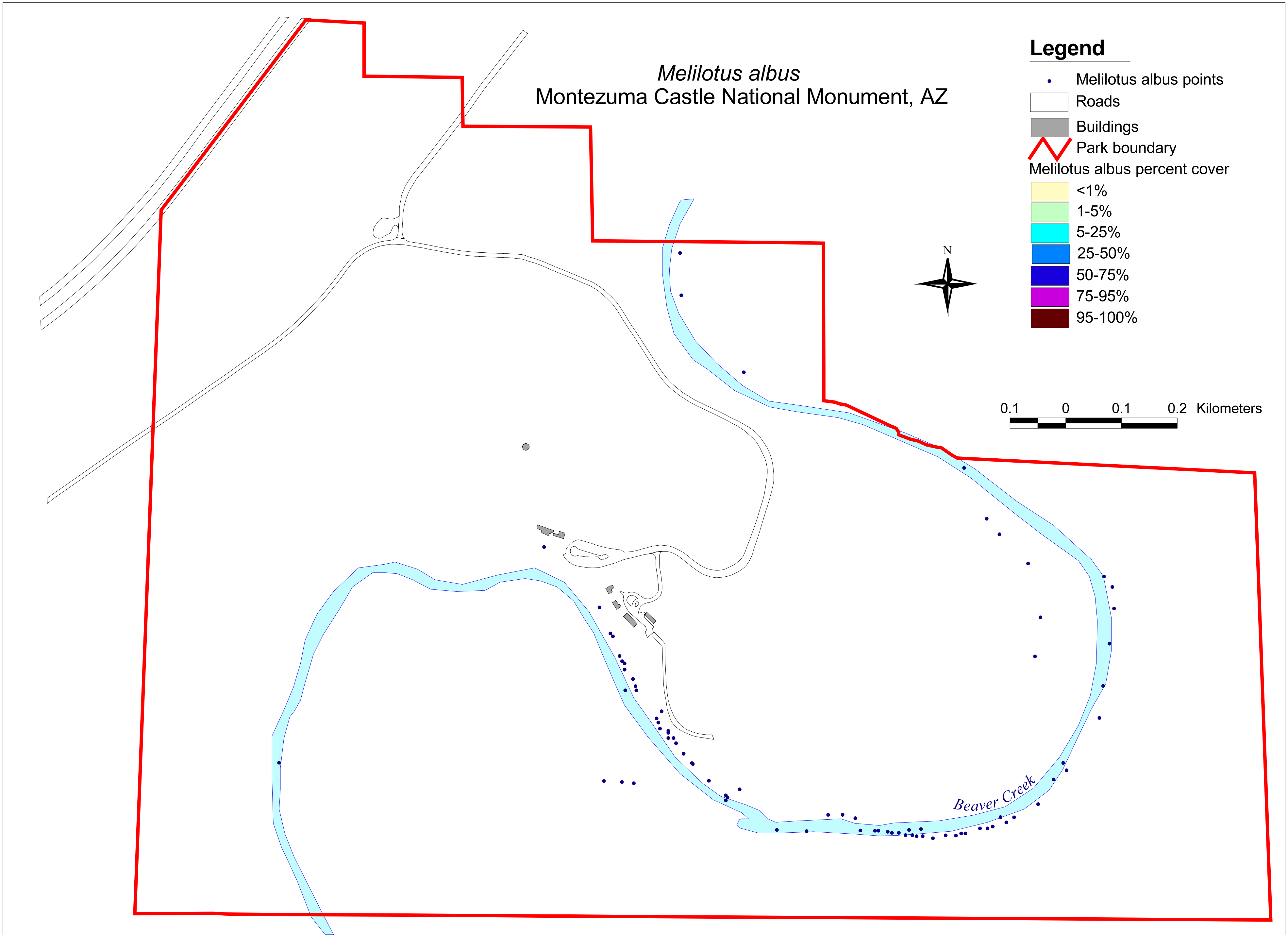

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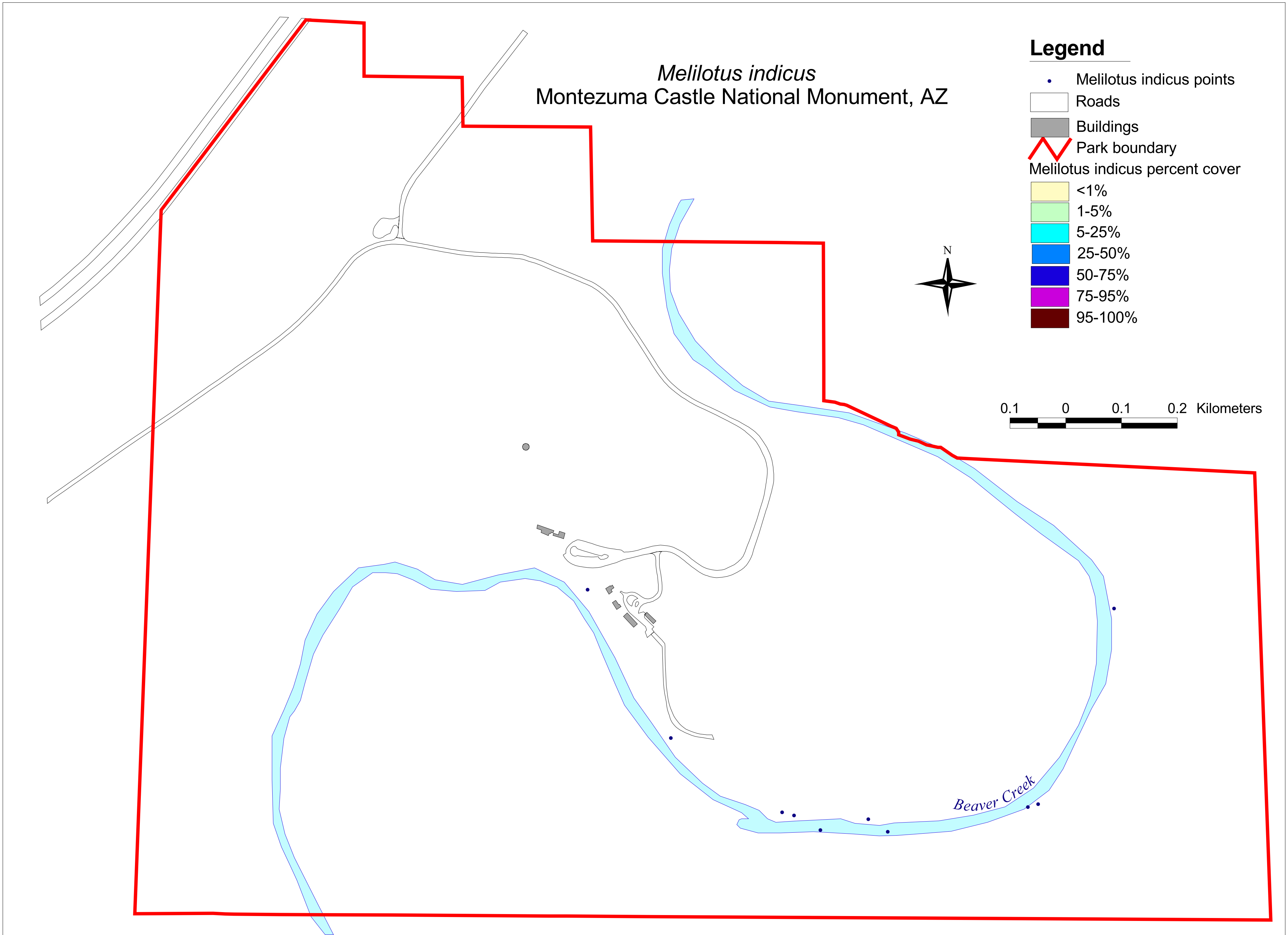

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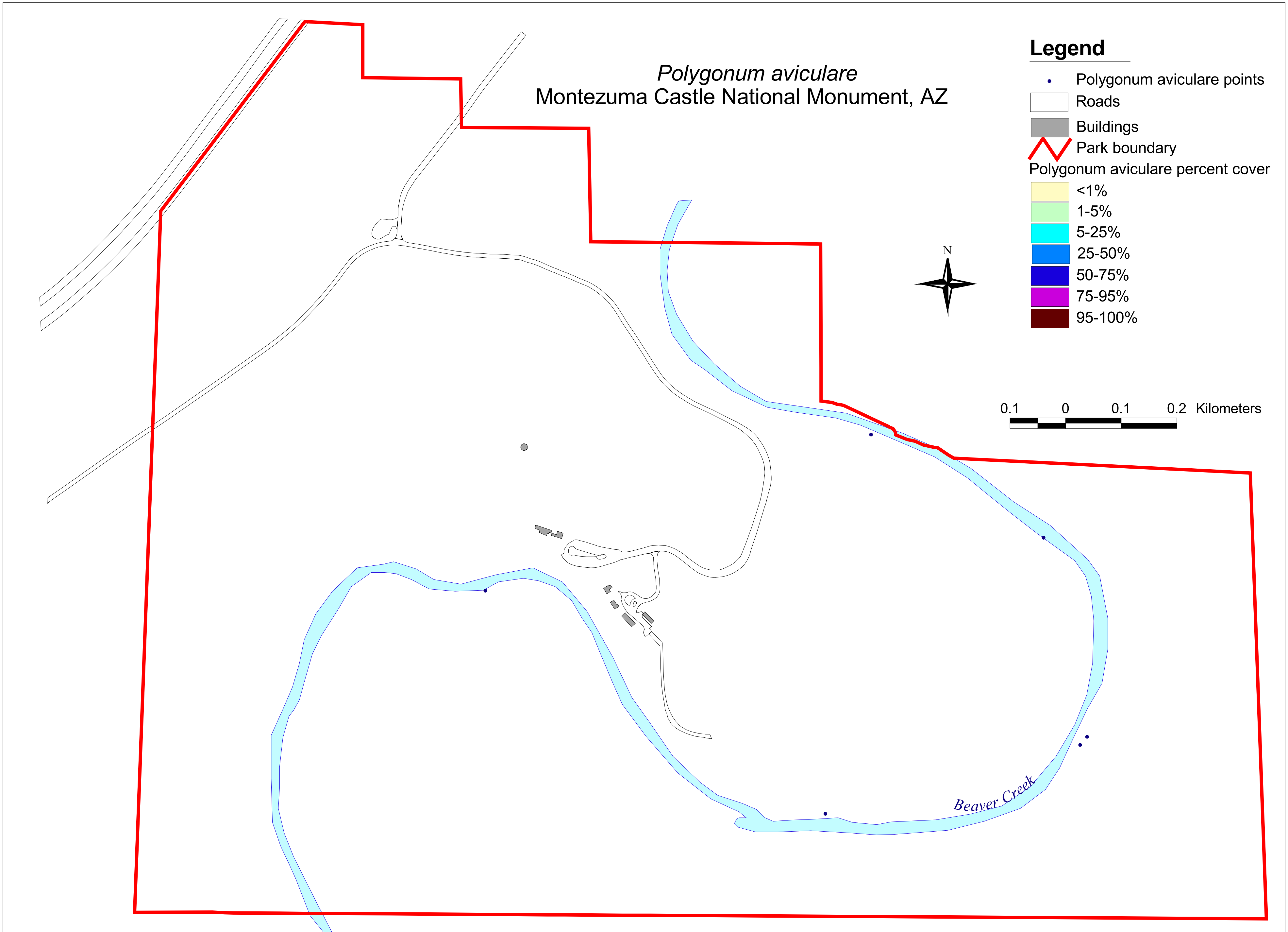

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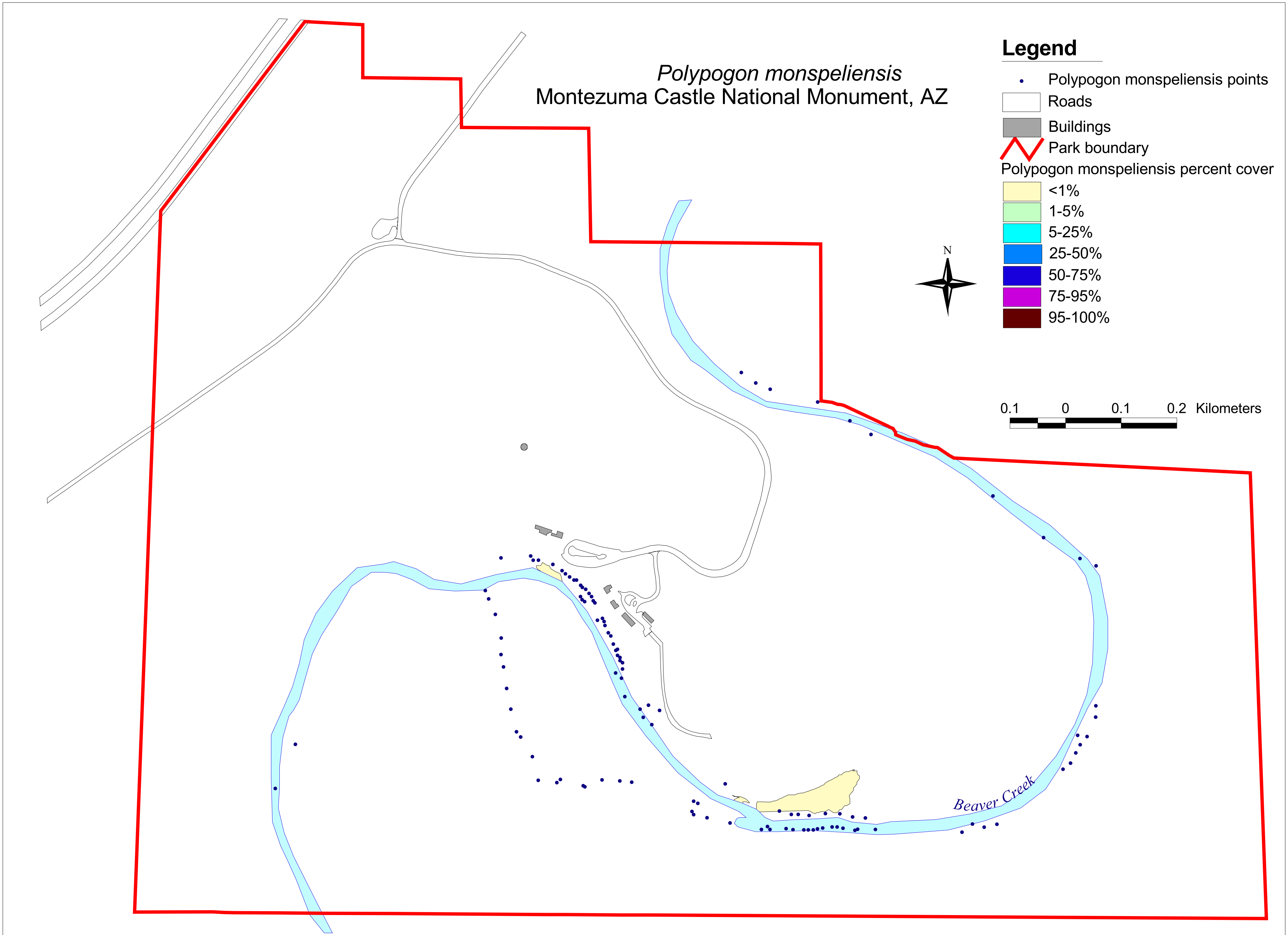

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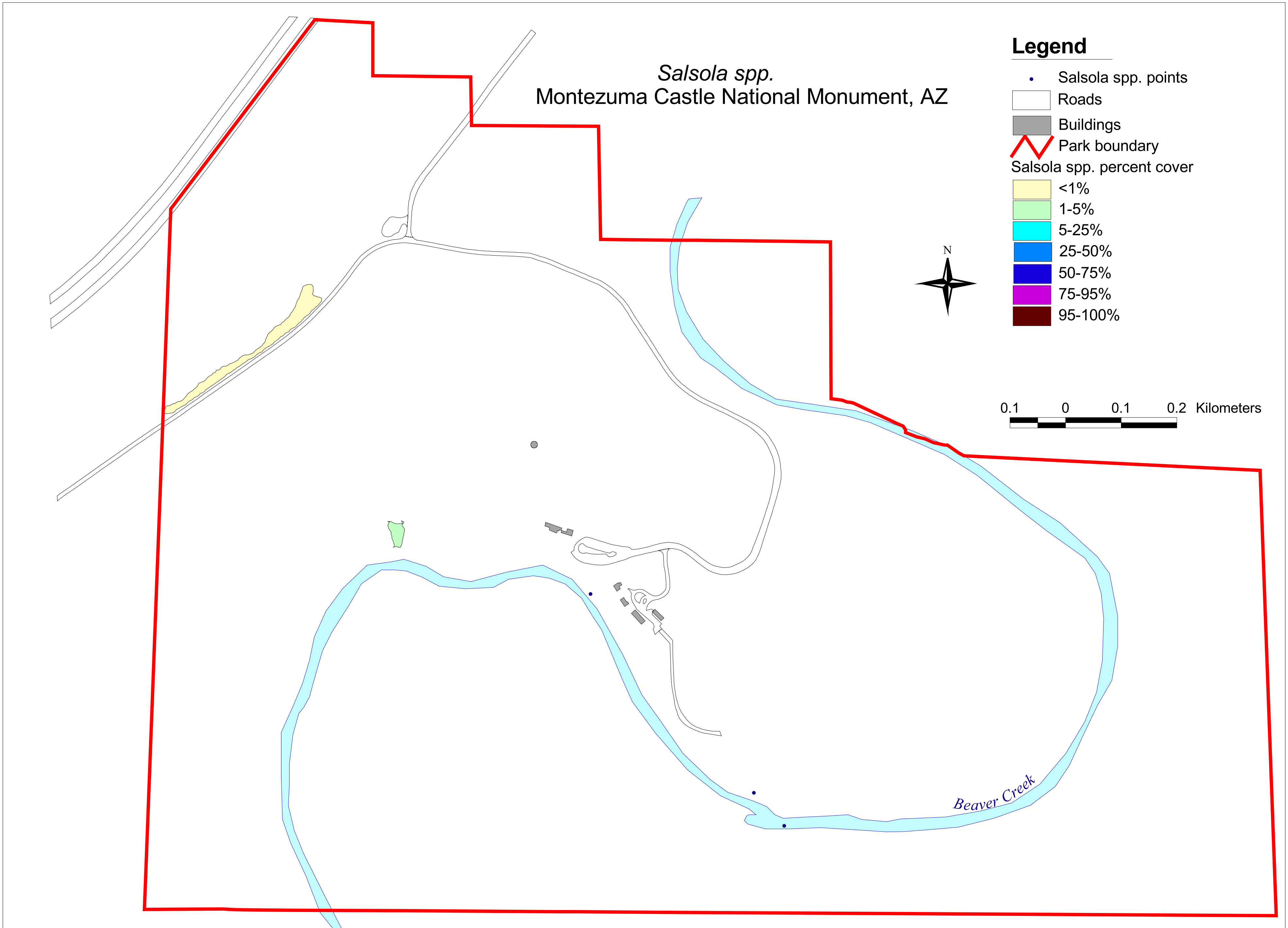

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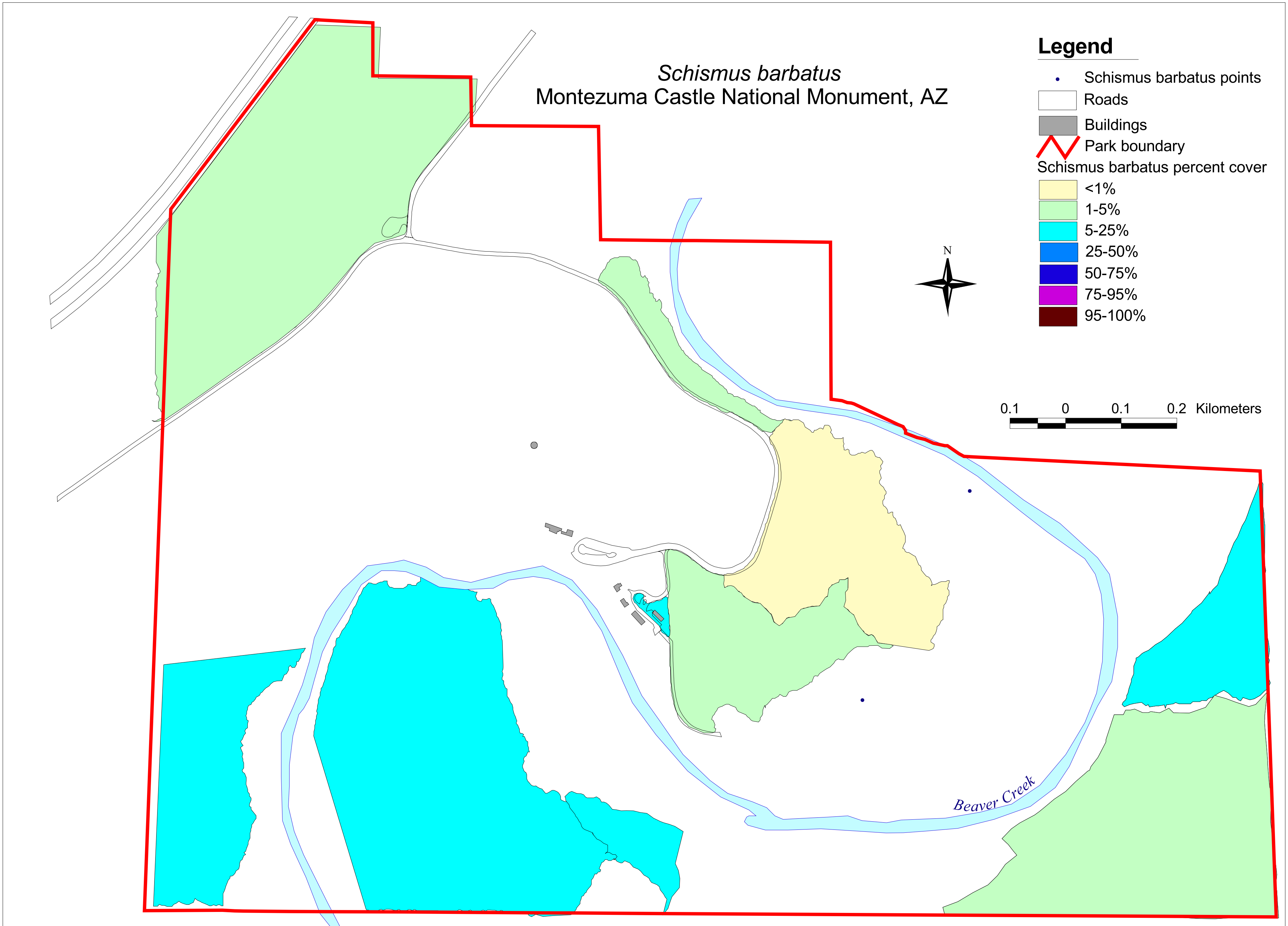

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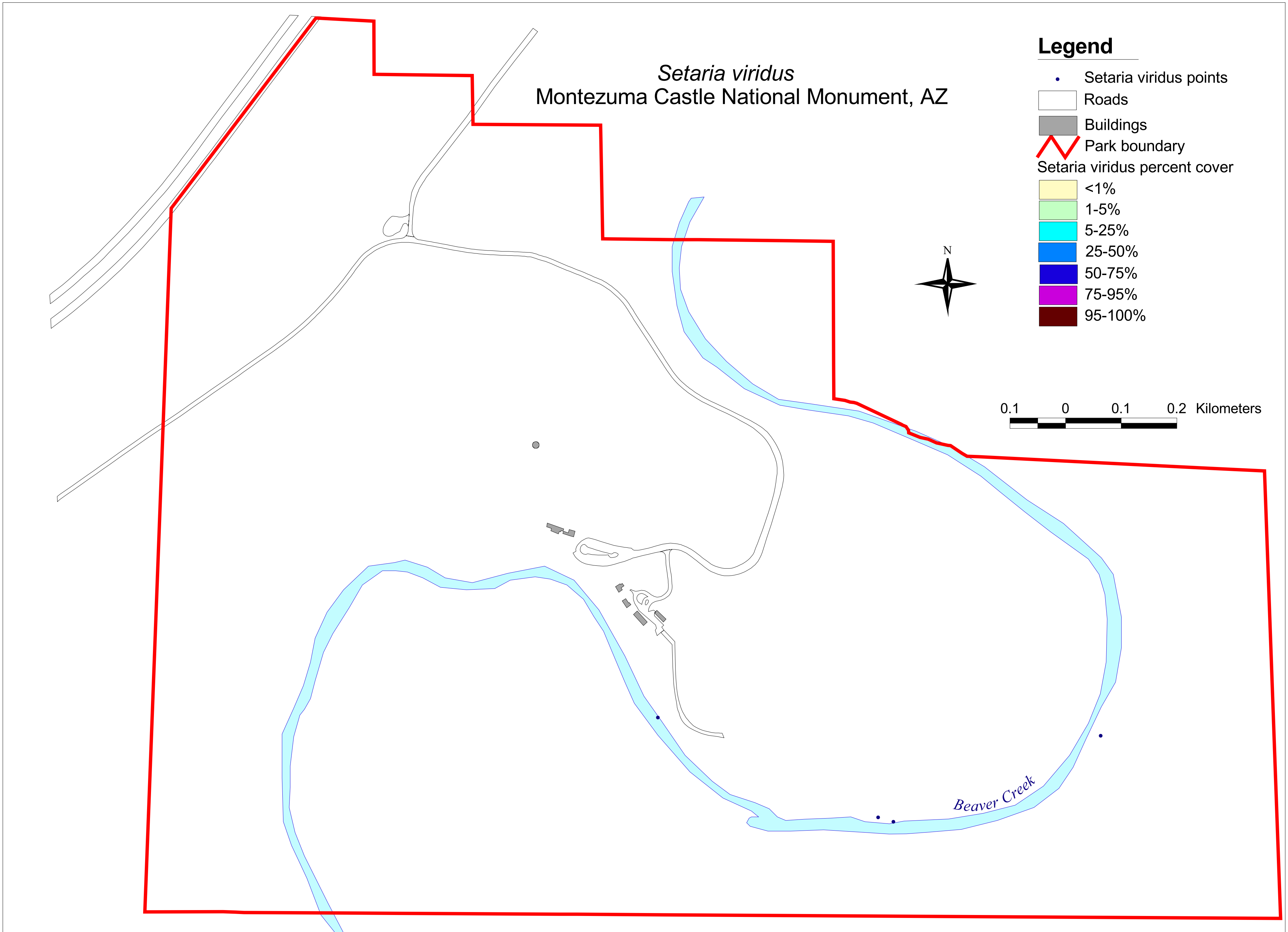

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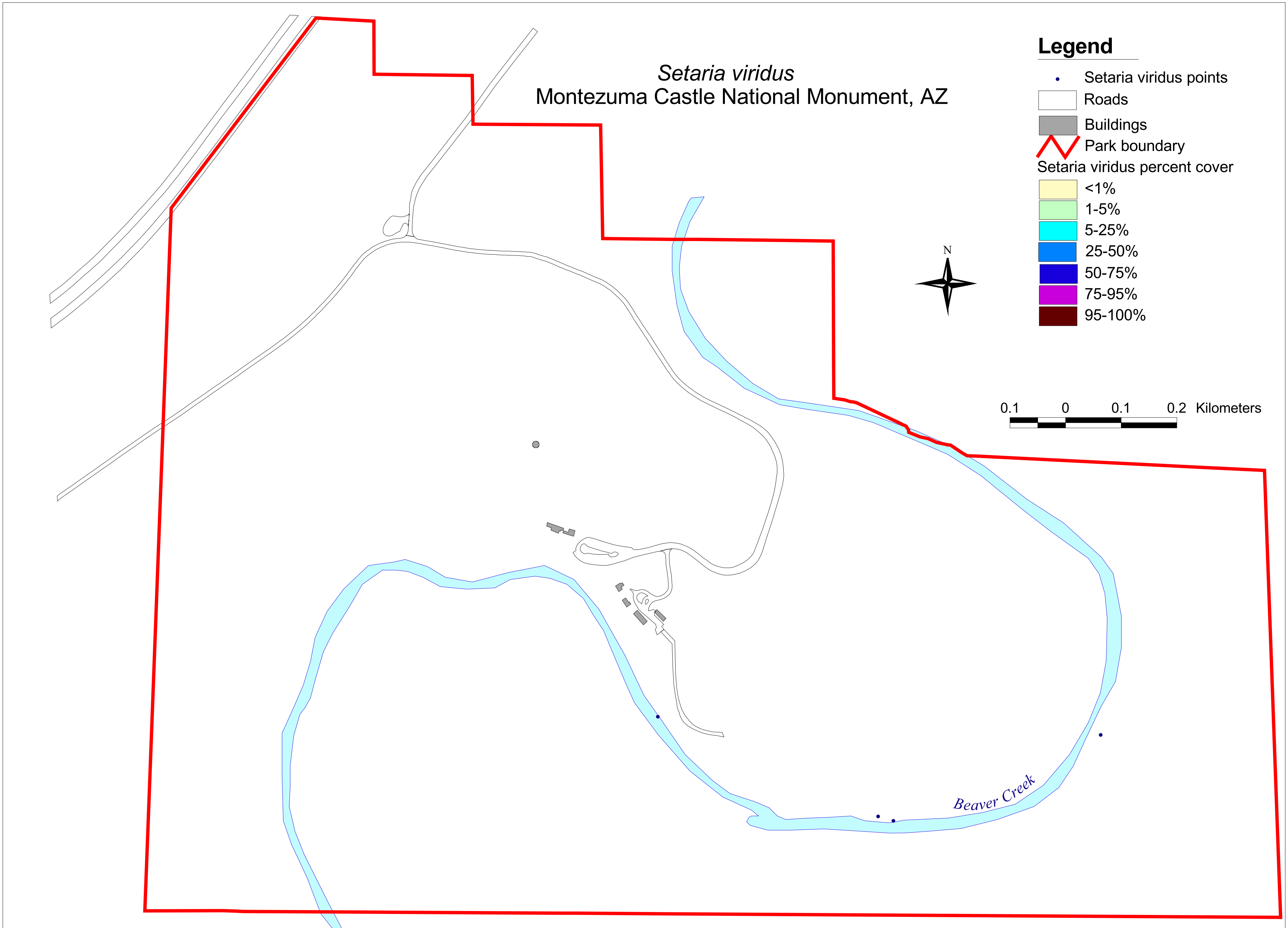

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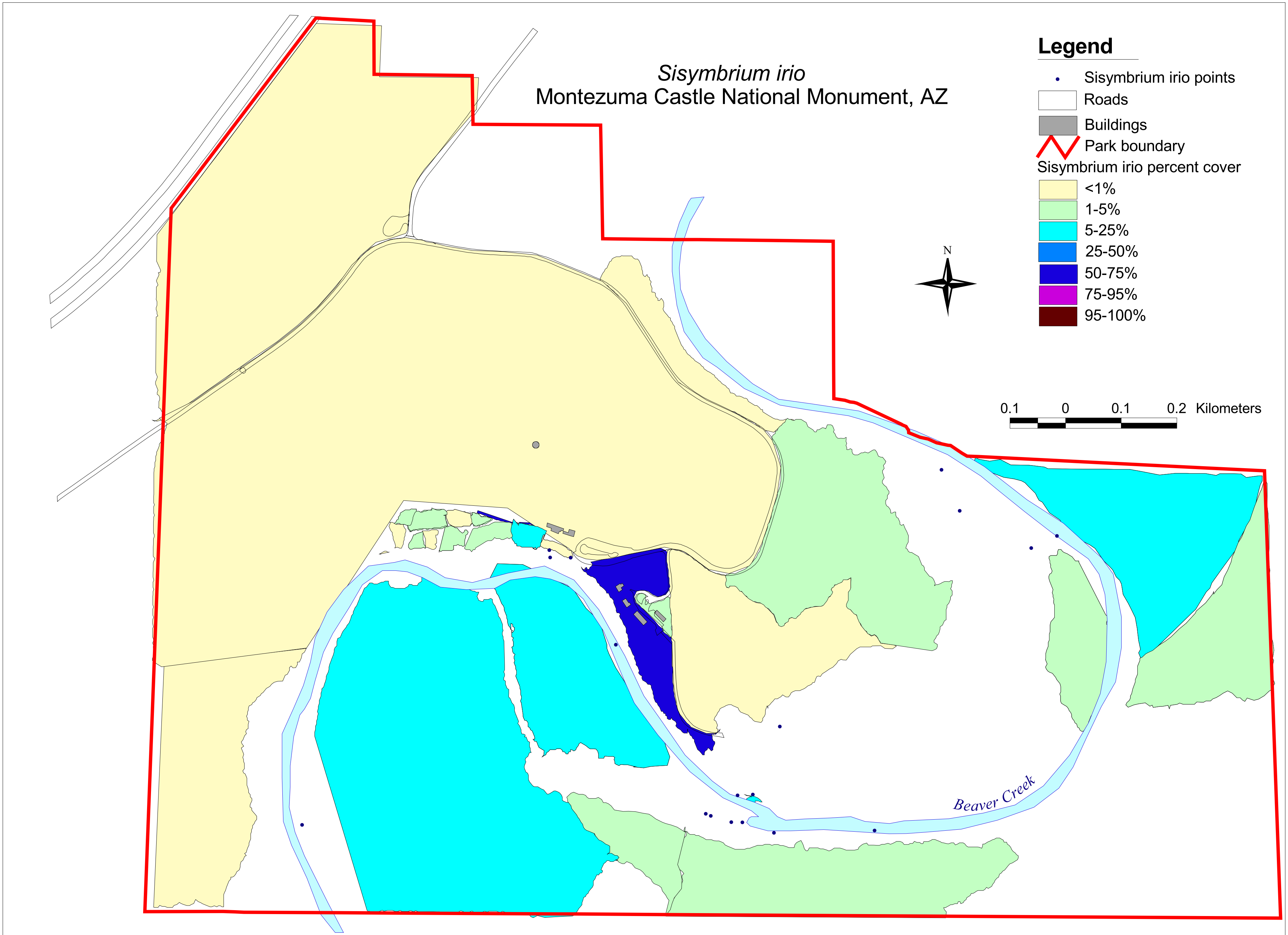

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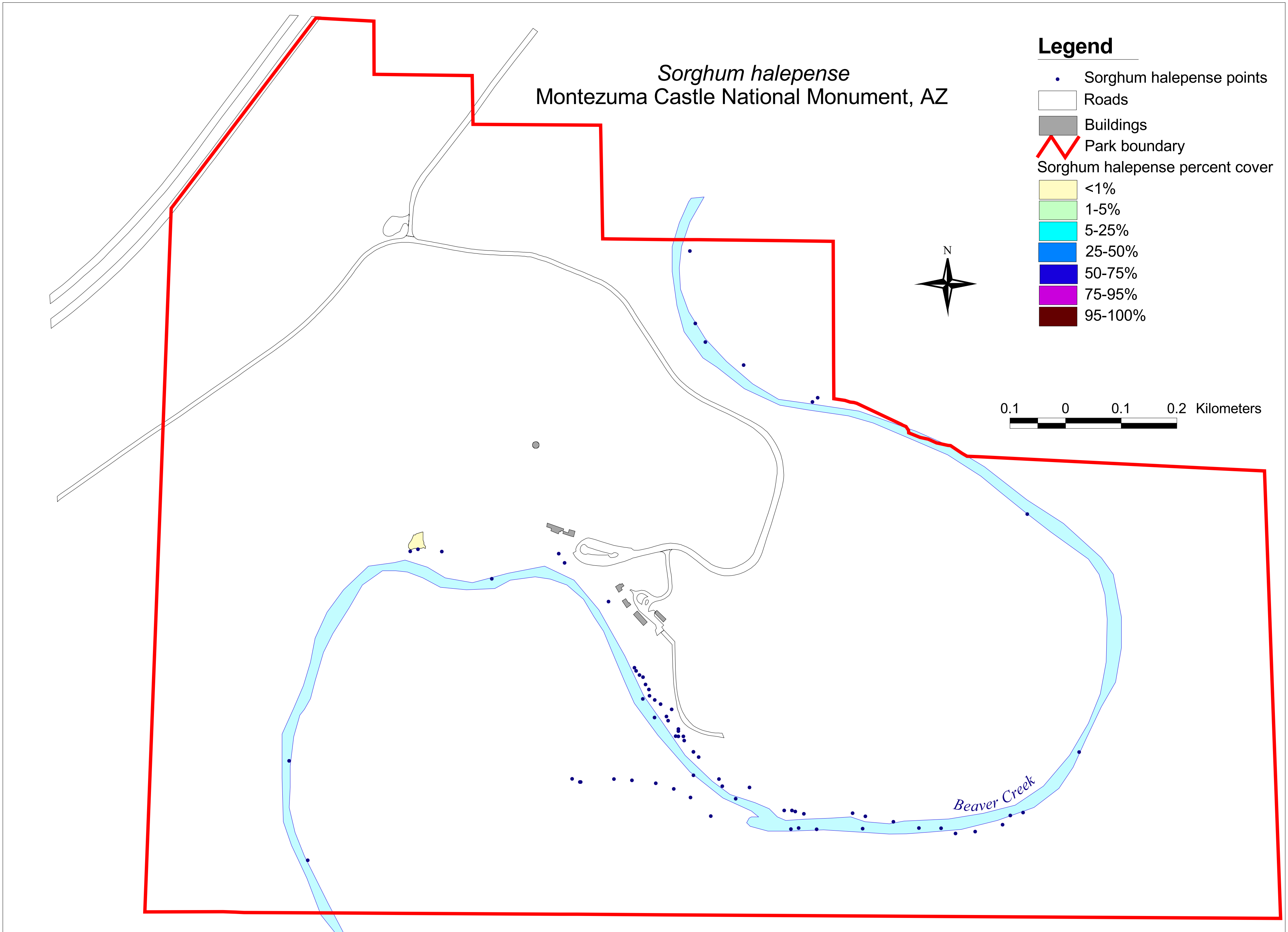

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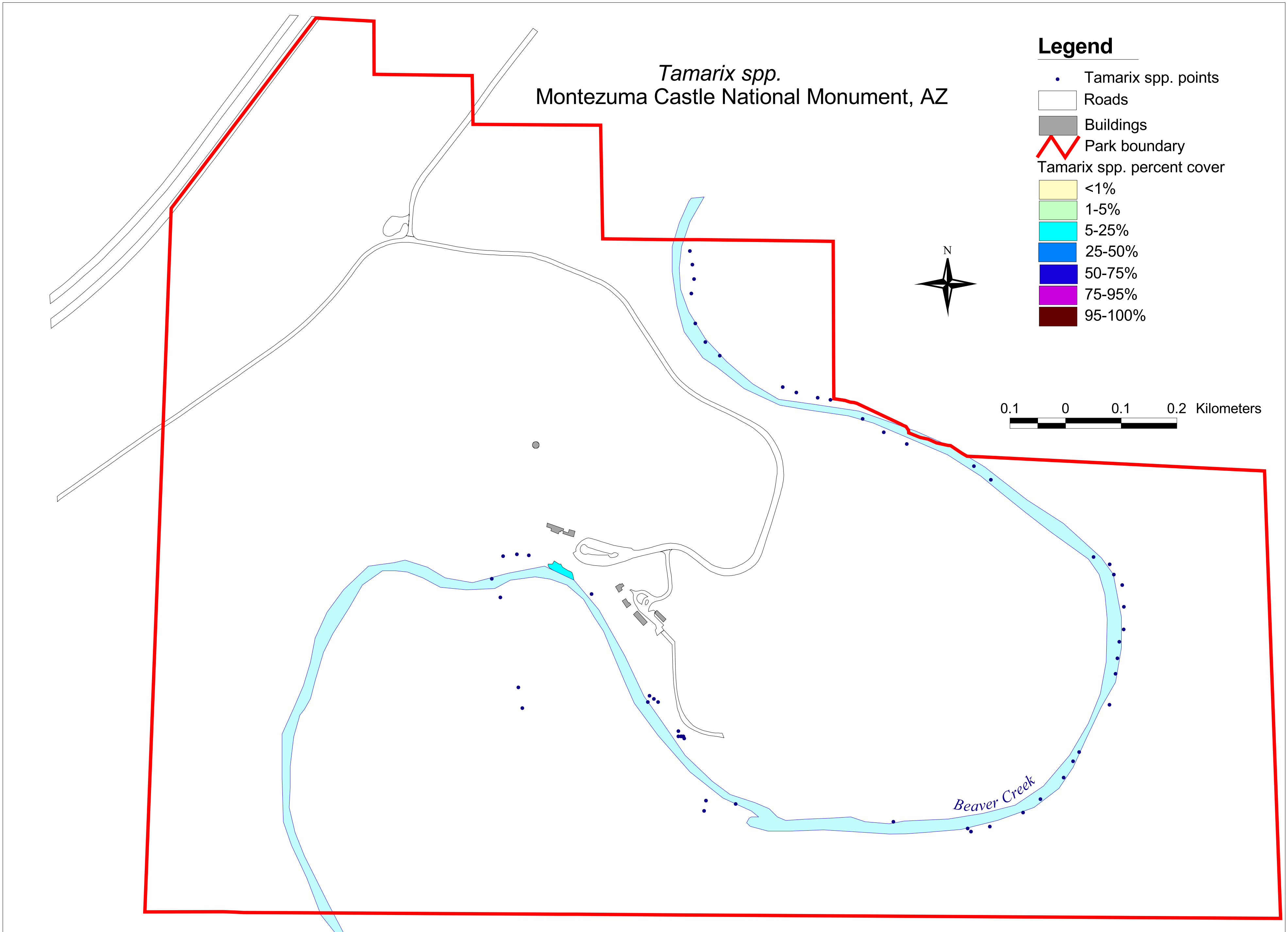

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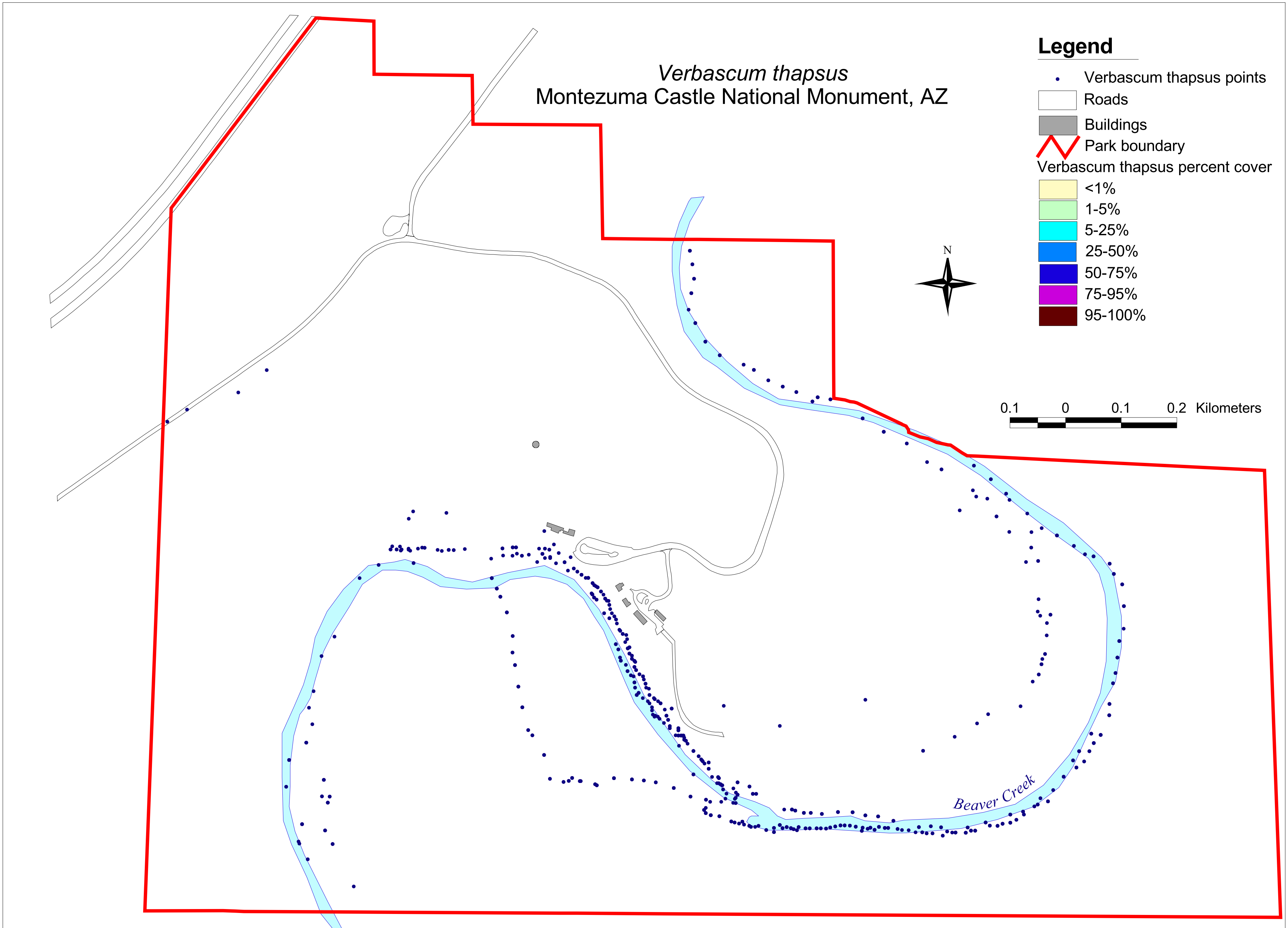

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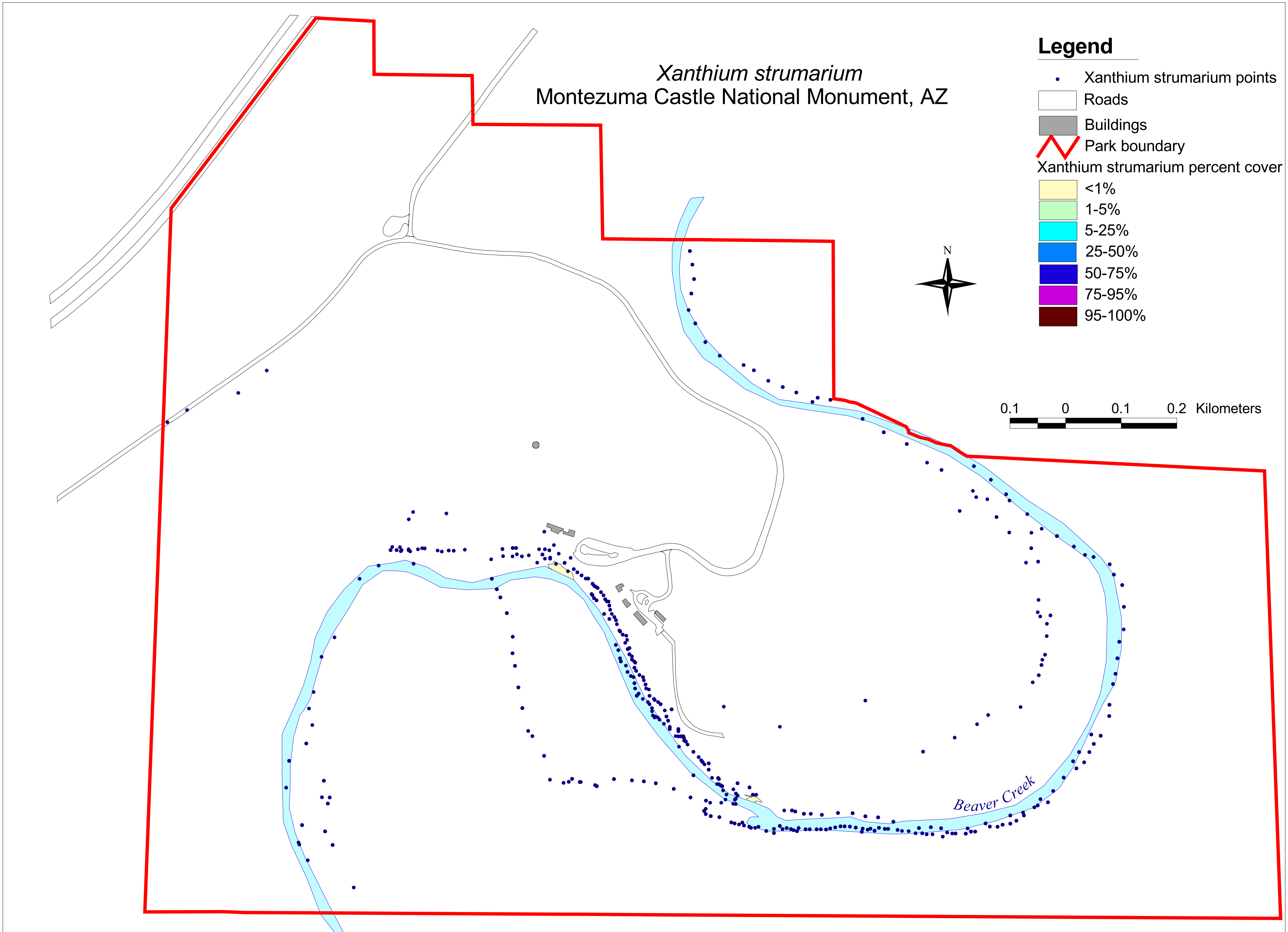

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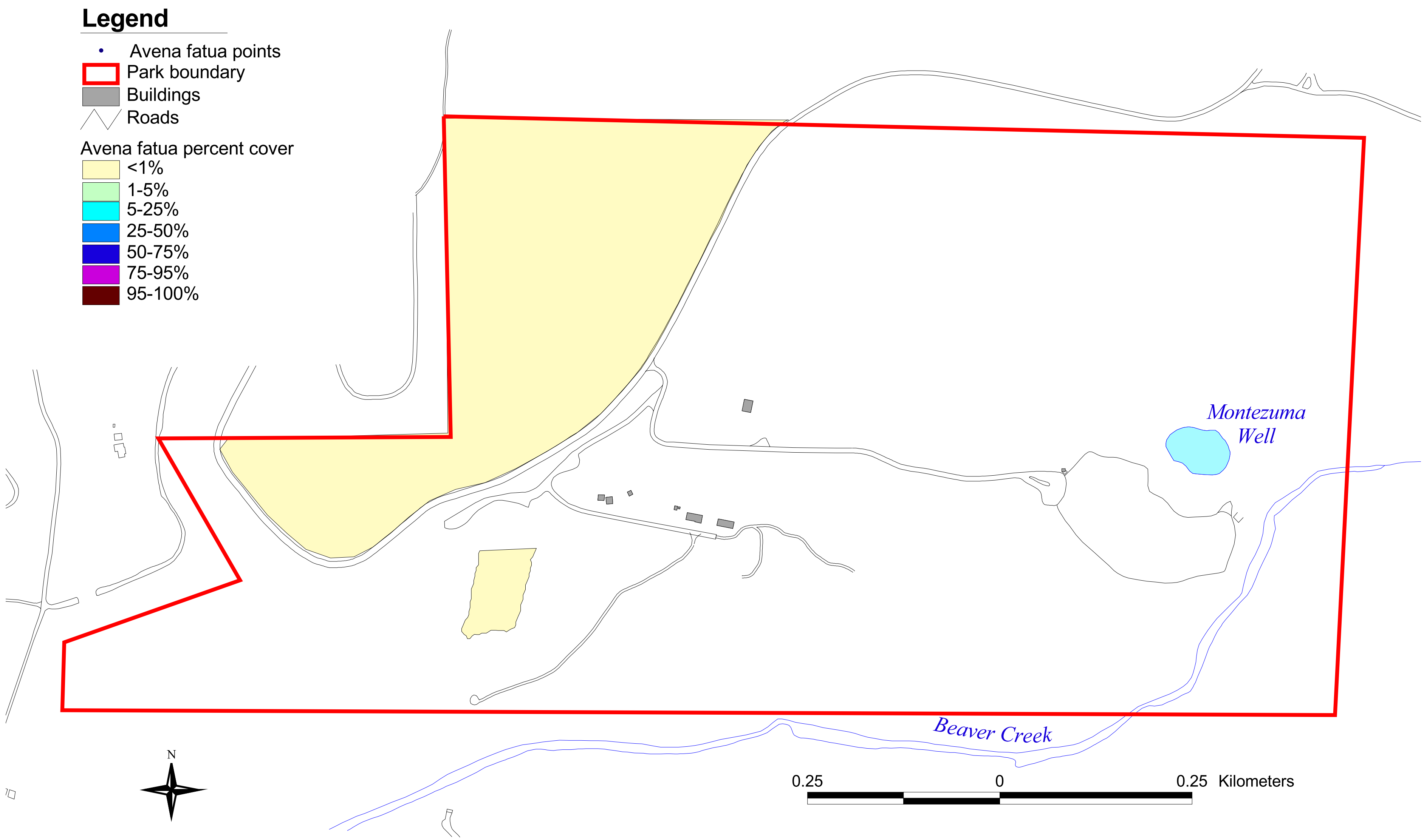
Avena fatua
Montezuma Castle National Monument, Well Unit, AZ



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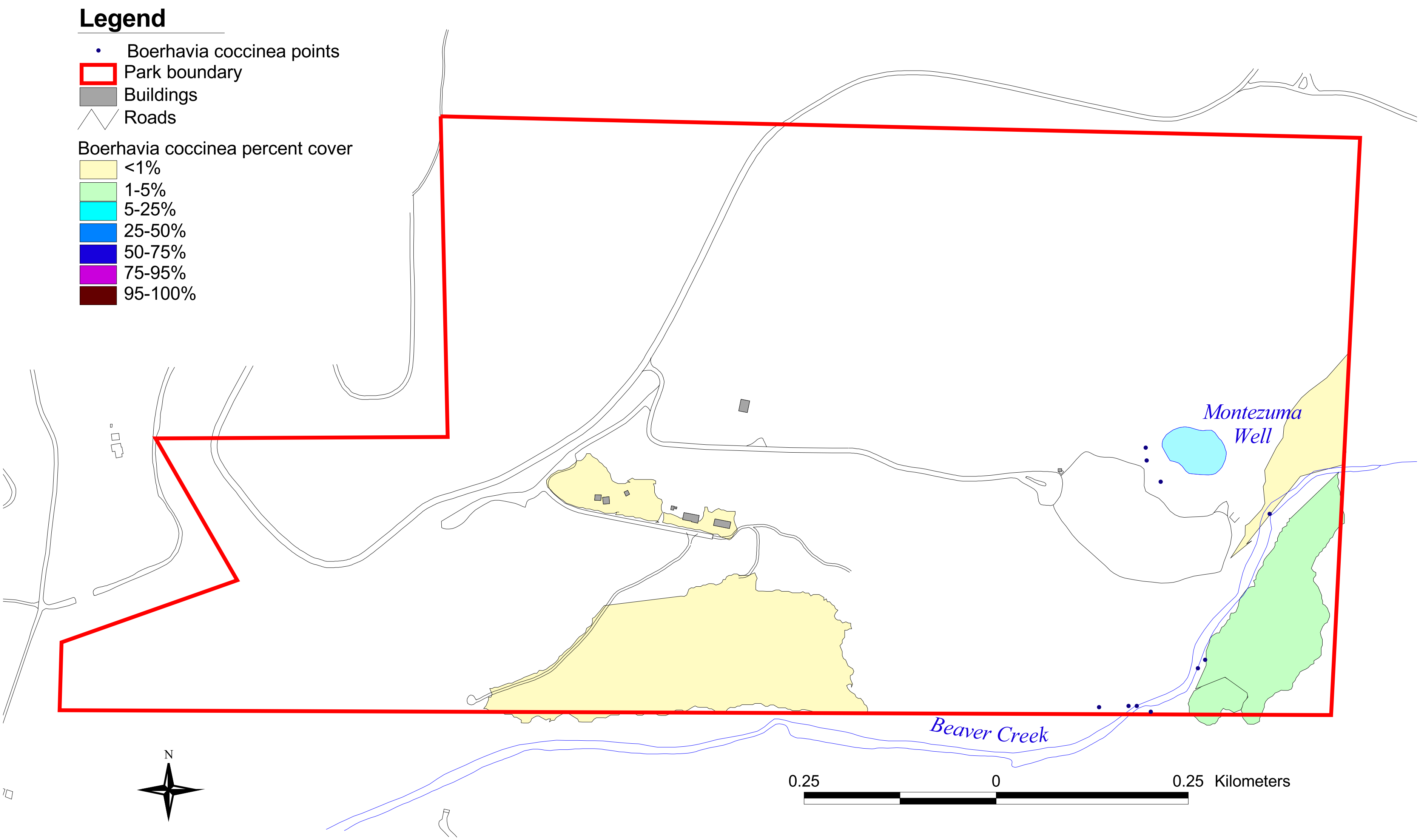
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Boerhavia coccinea
Montezuma Castle National Monument, Well Unit, AZ



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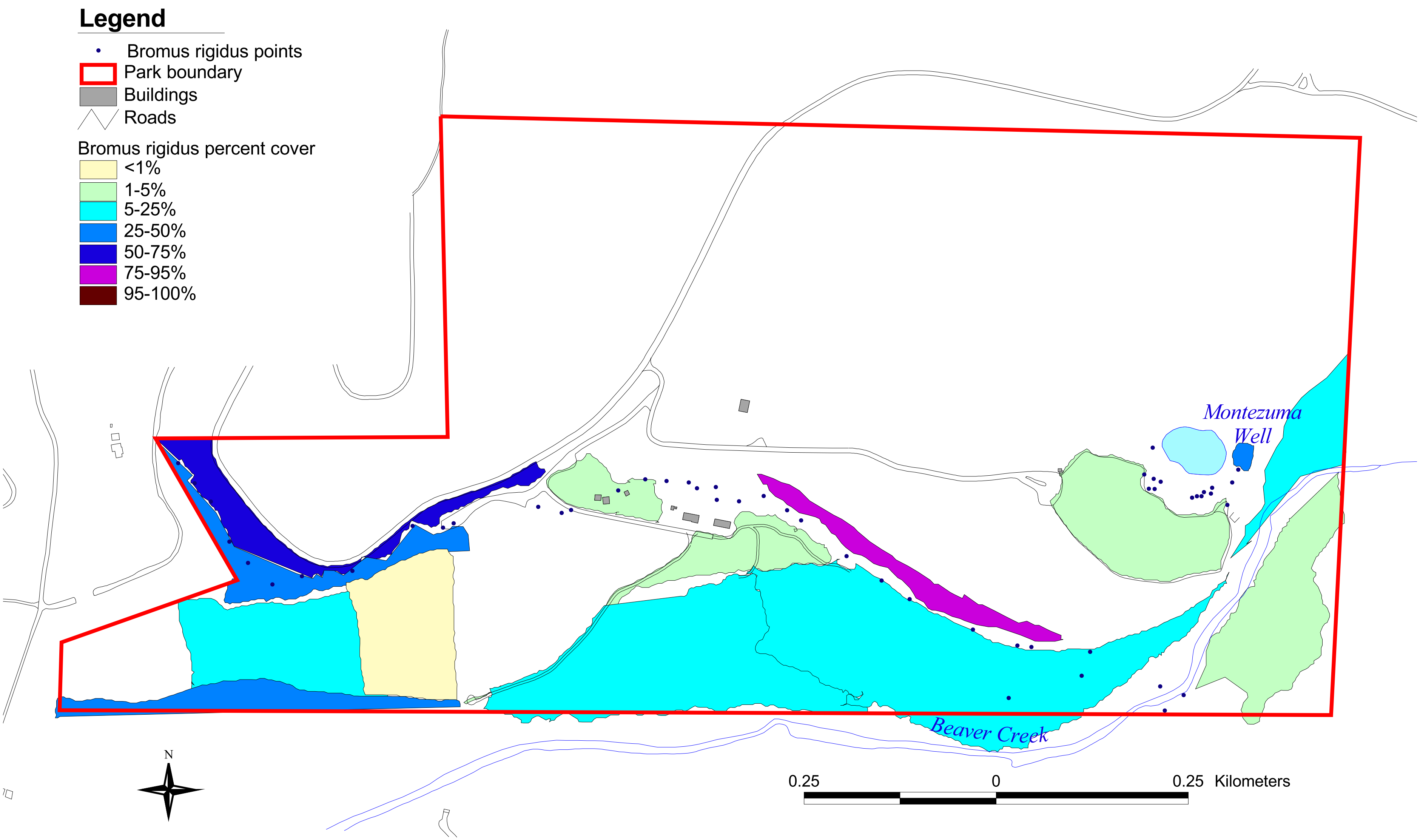
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Brassica tournefortii
Montezuma Castle National Monument, Well Unit, AZ

Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

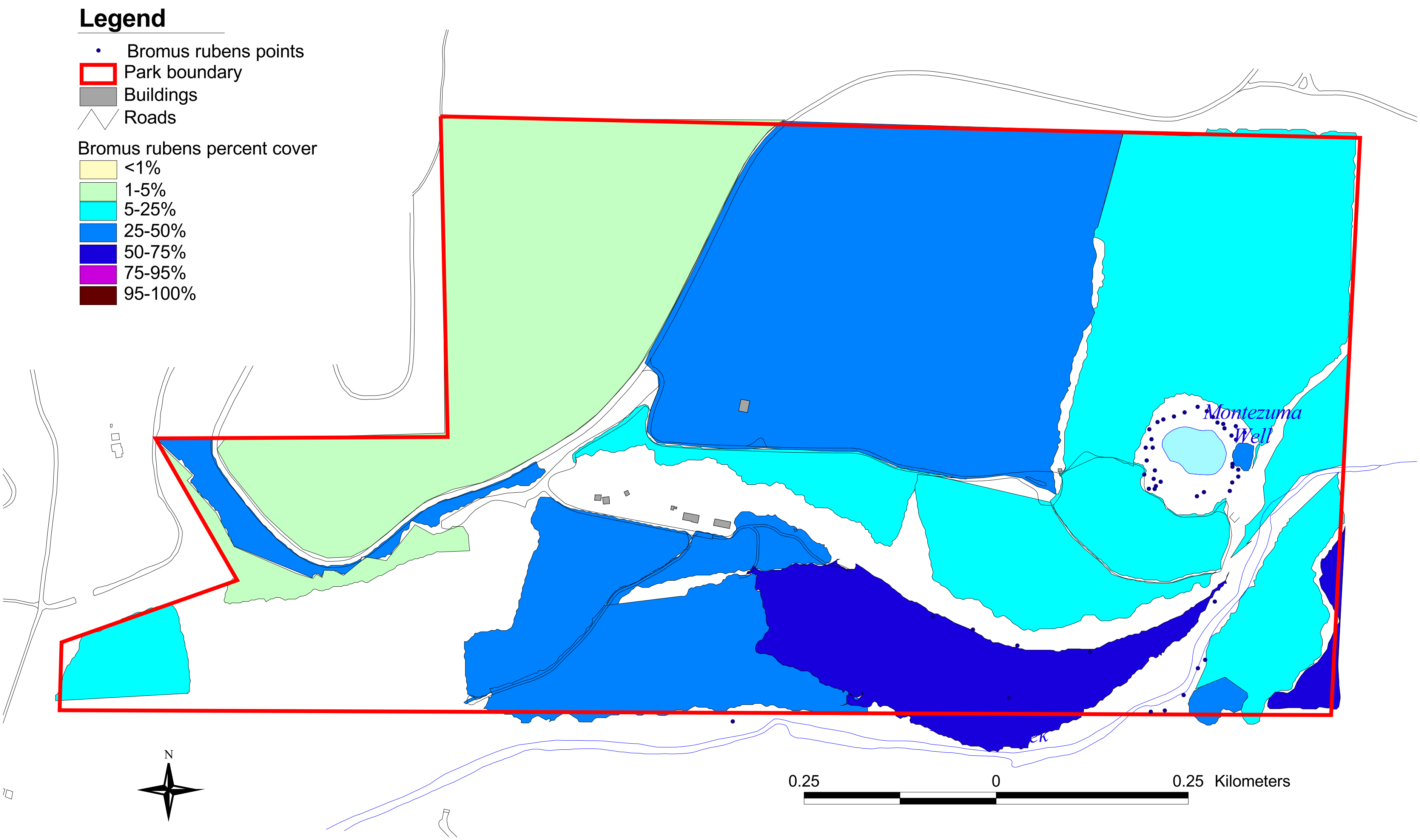
Bromus rigidus

Montezuma Castle National Monument, Well Unit, AZ



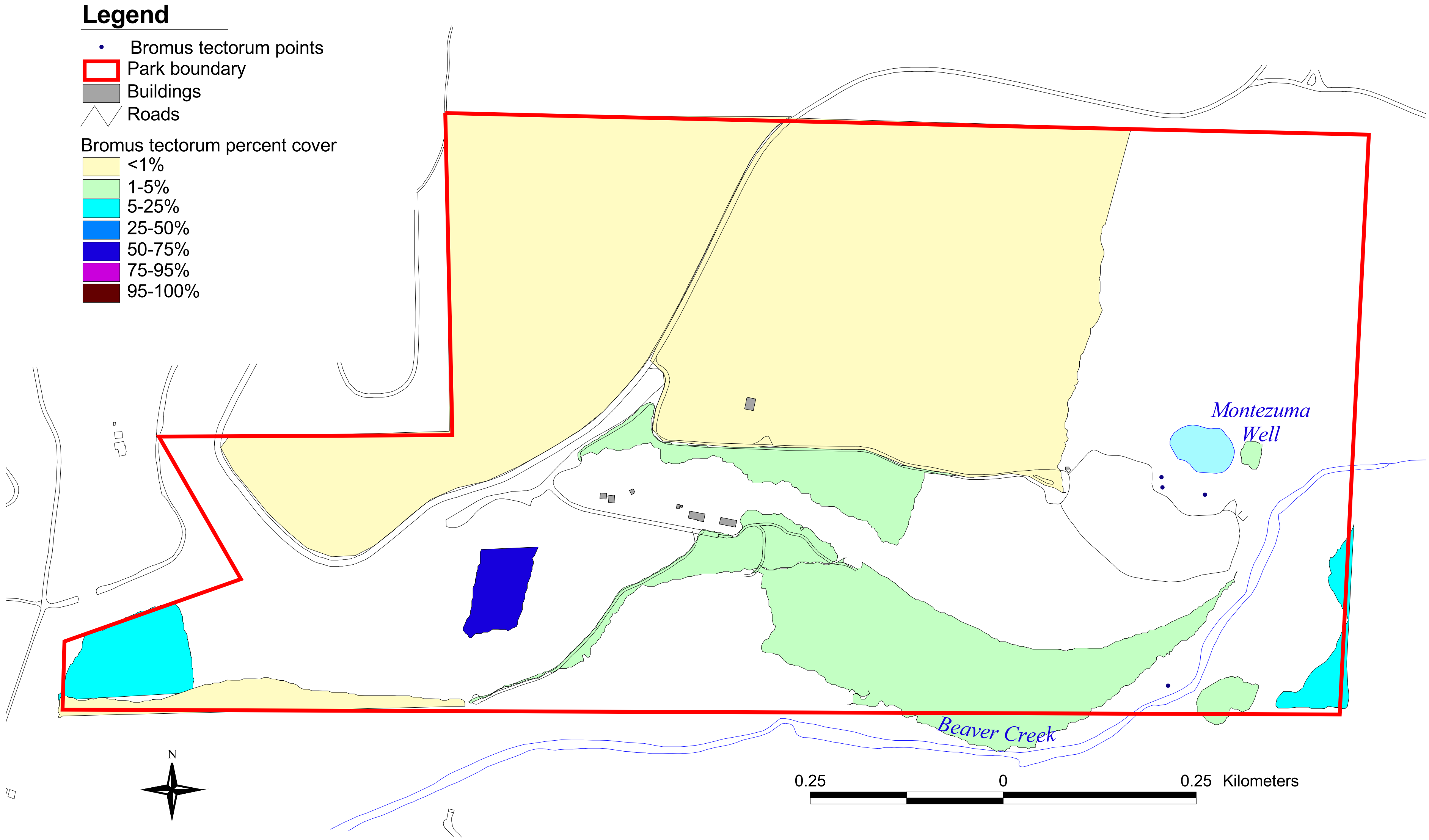
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Bromus rubens
Montezuma Castle National Monument, Well Unit, AZ



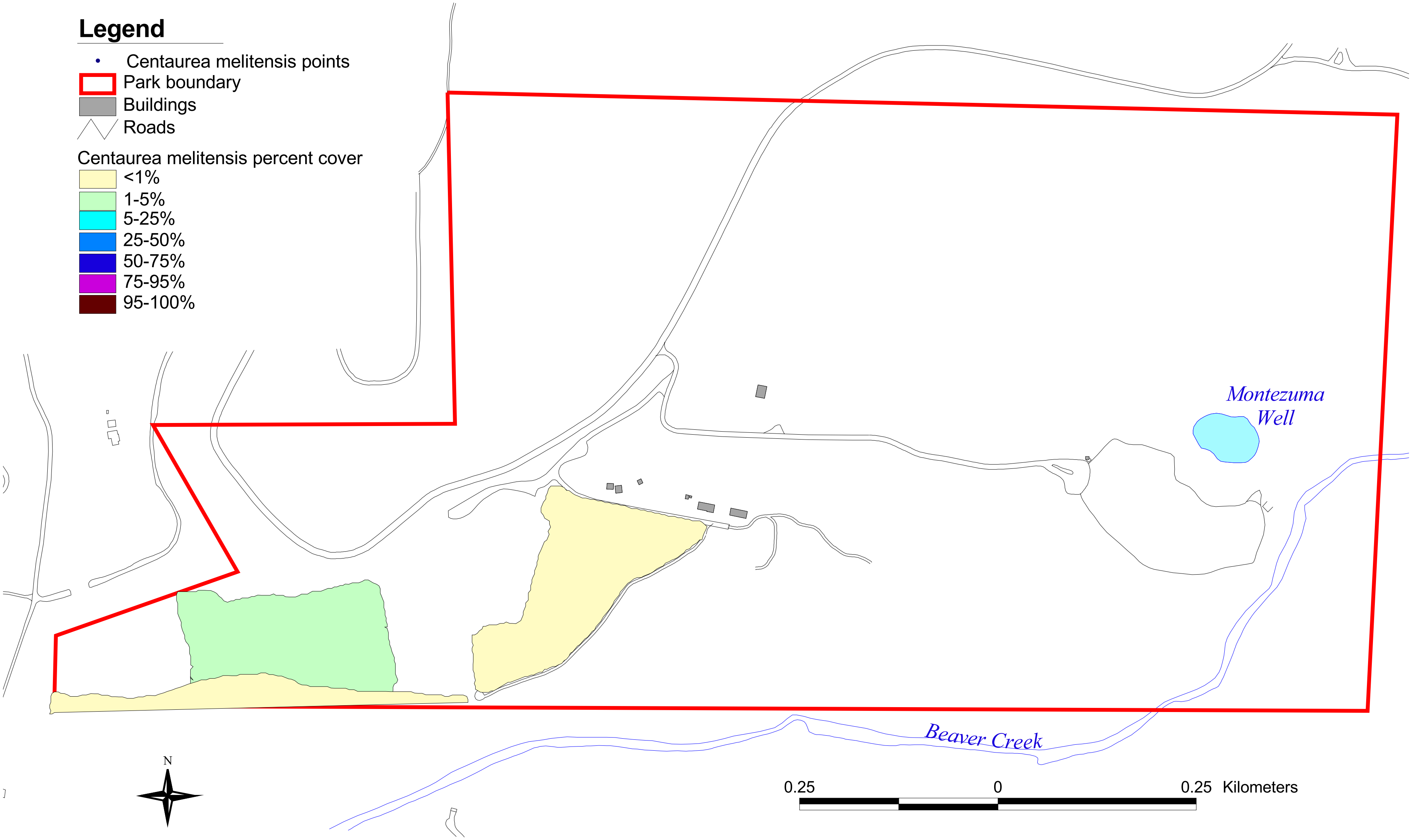
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Bromus tectorum
Montezuma Castle National Monument, Well Unit, AZ



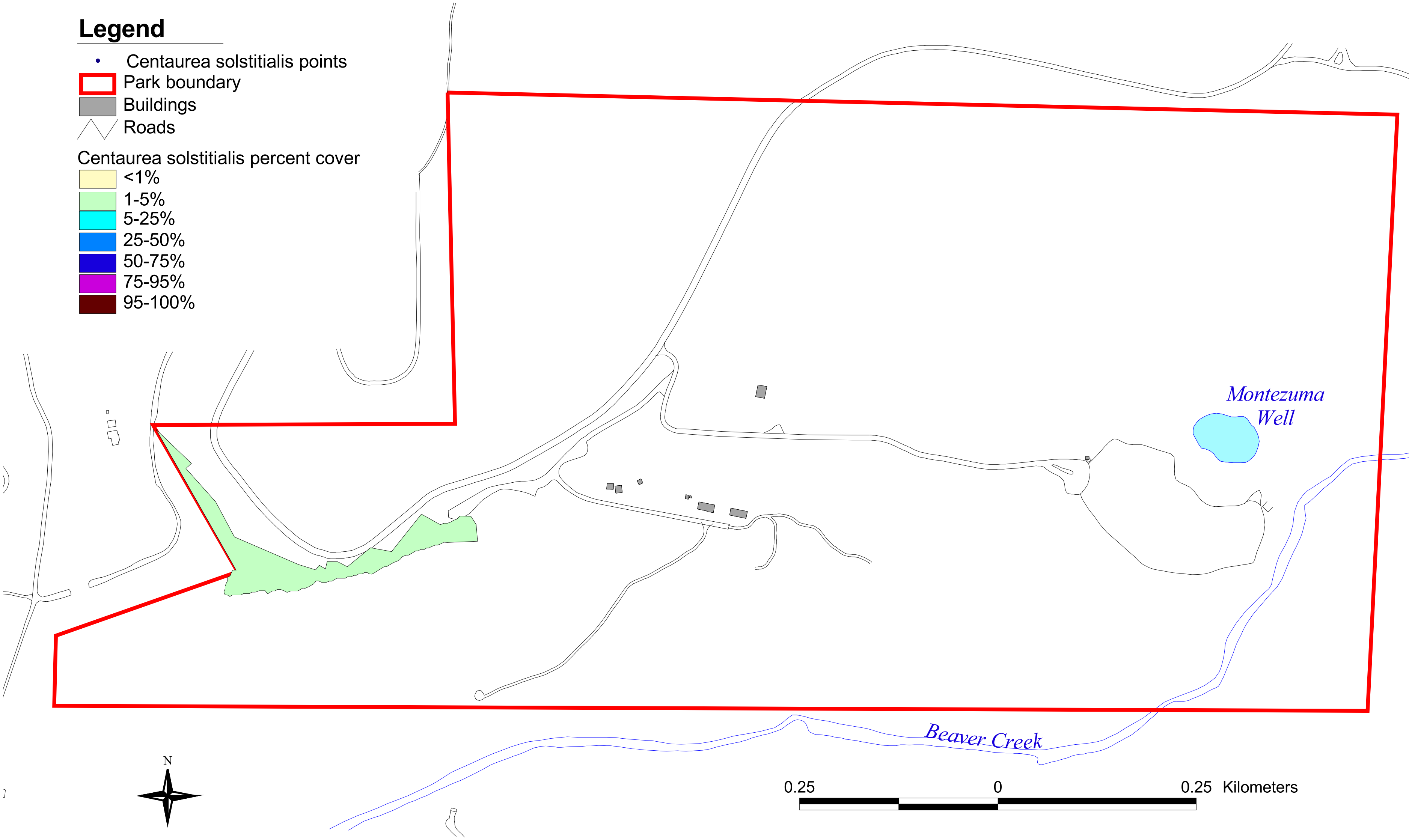
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Centaurea melitensis
Montezuma Castle National Monument, Well Unit, AZ



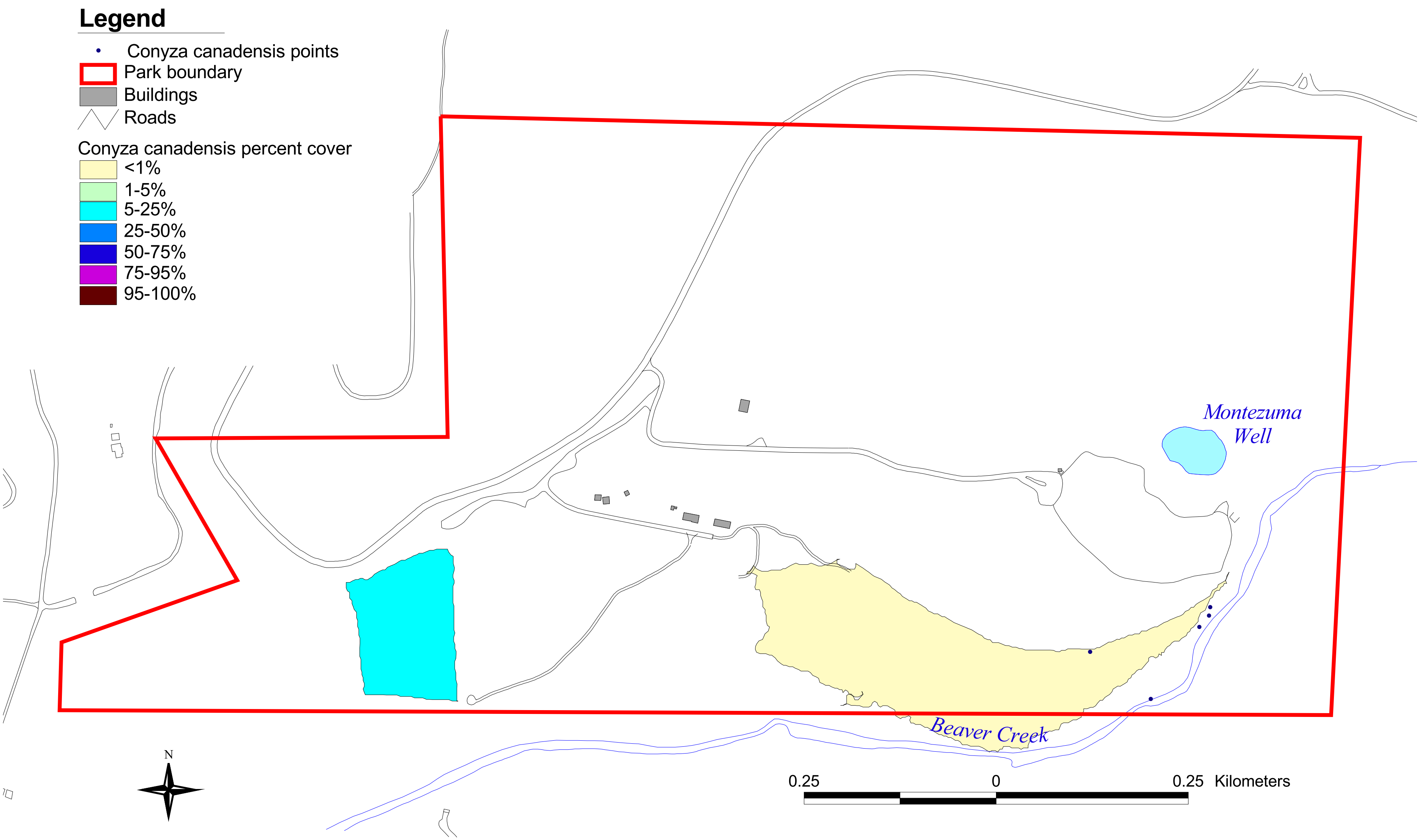
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Centaurea solstitialis
Montezuma Castle National Monument, Well Unit, AZ



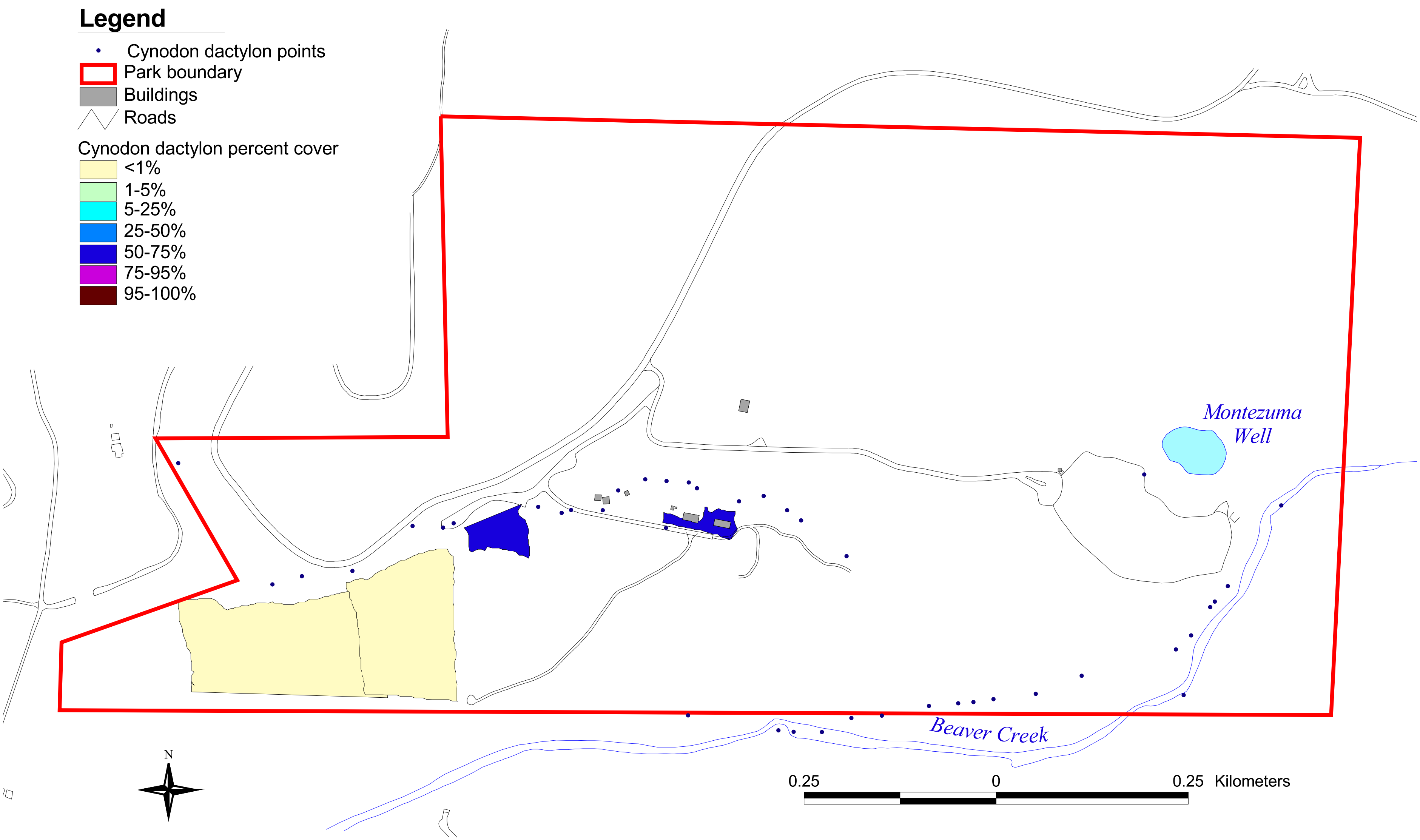
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Conyza canadensis
Montezuma Castle National Monument, Well Unit, AZ



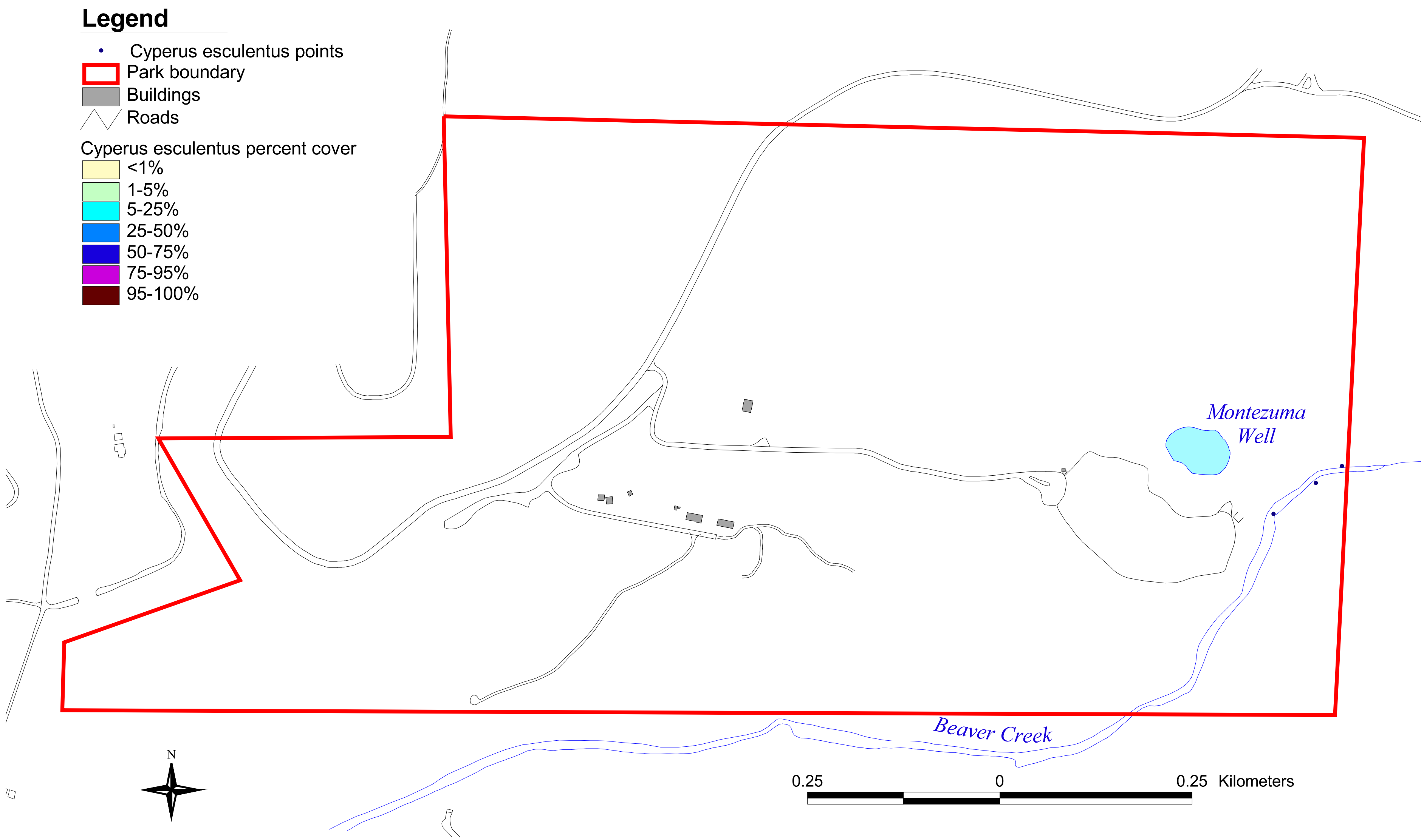
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Cynodon dactylon
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Cyperus esculentus
Montezuma Castle National Monument, Well Unit, AZ

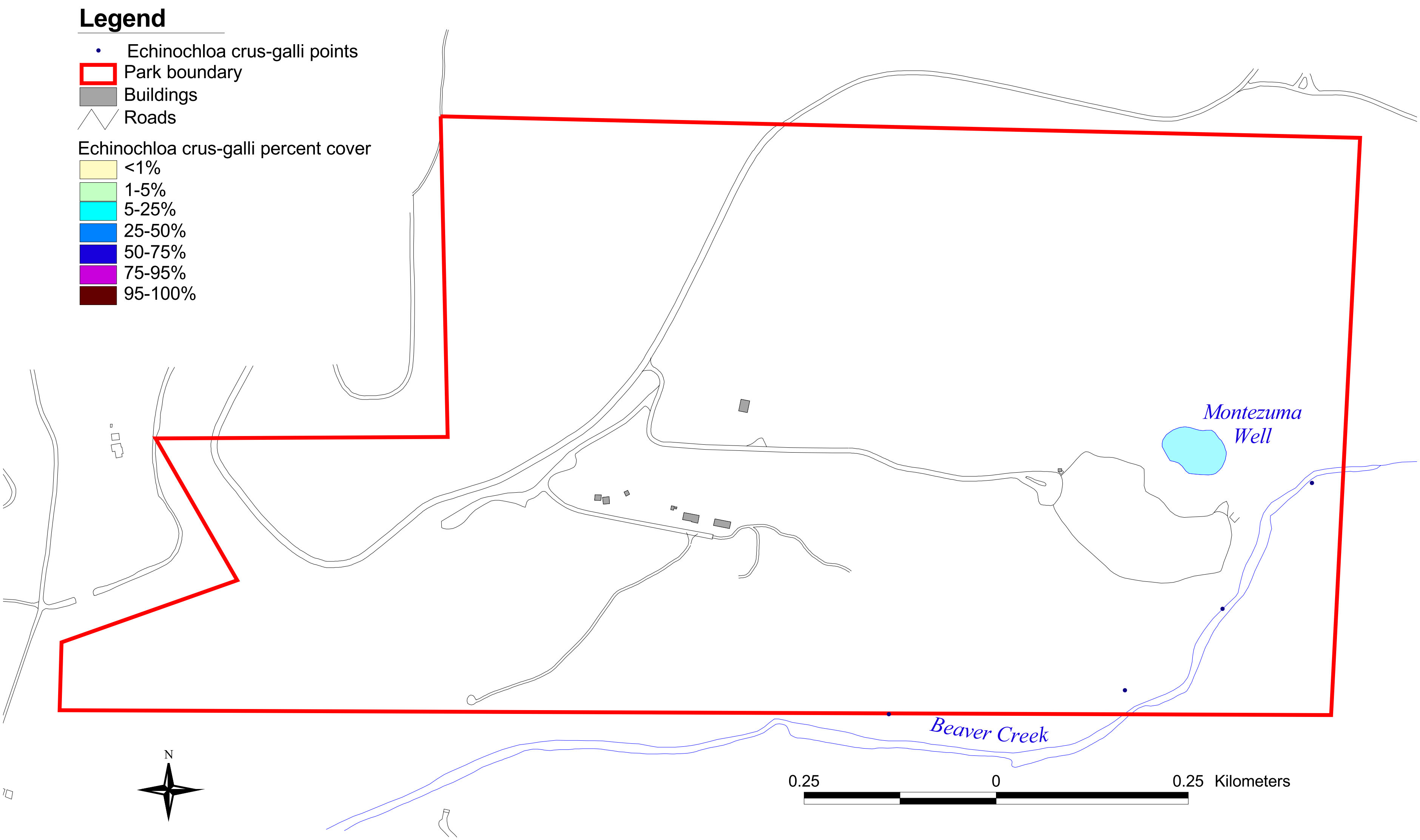


Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Digitaria sanguinalis
Montezuma Castle National Monument, Well Unit, AZ

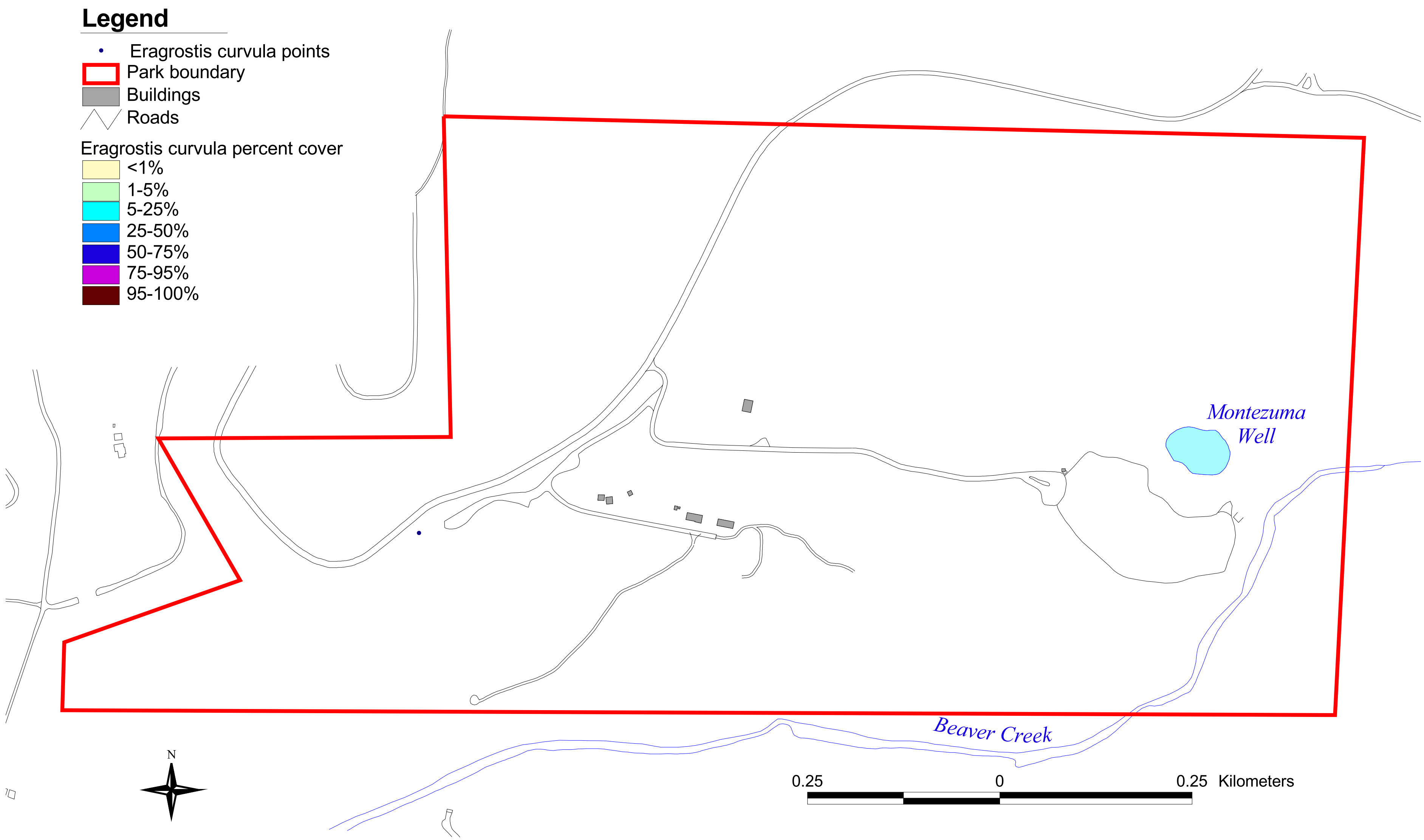
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Echinochloa crus-galli
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Eragrostis curvula
Montezuma Castle National Monument, Well Unit, AZ

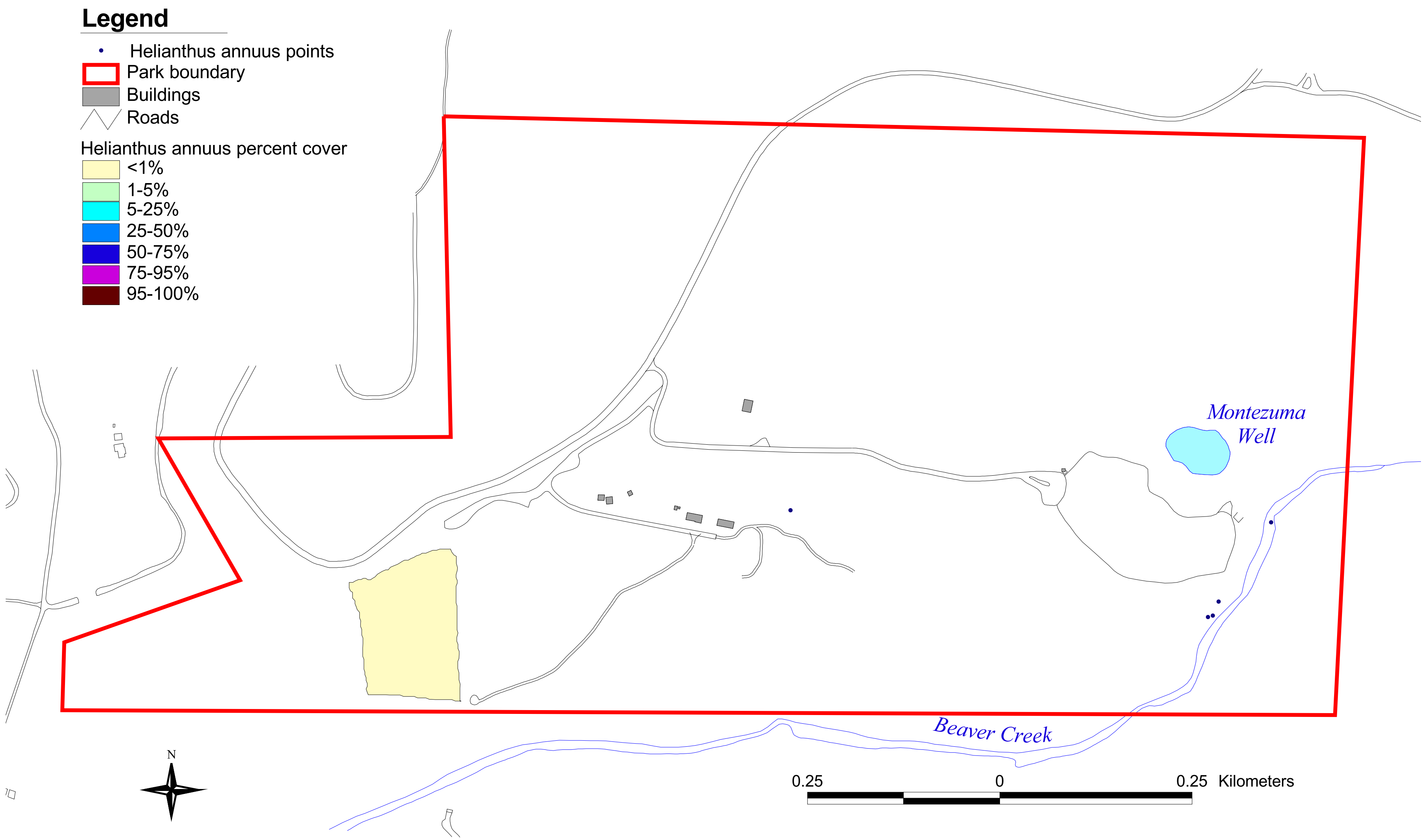


Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Erodium cicutarium
Montezuma Castle National Monument, Well Unit, AZ

Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Helianthus annuus
Montezuma Castle National Monument, Well Unit, AZ



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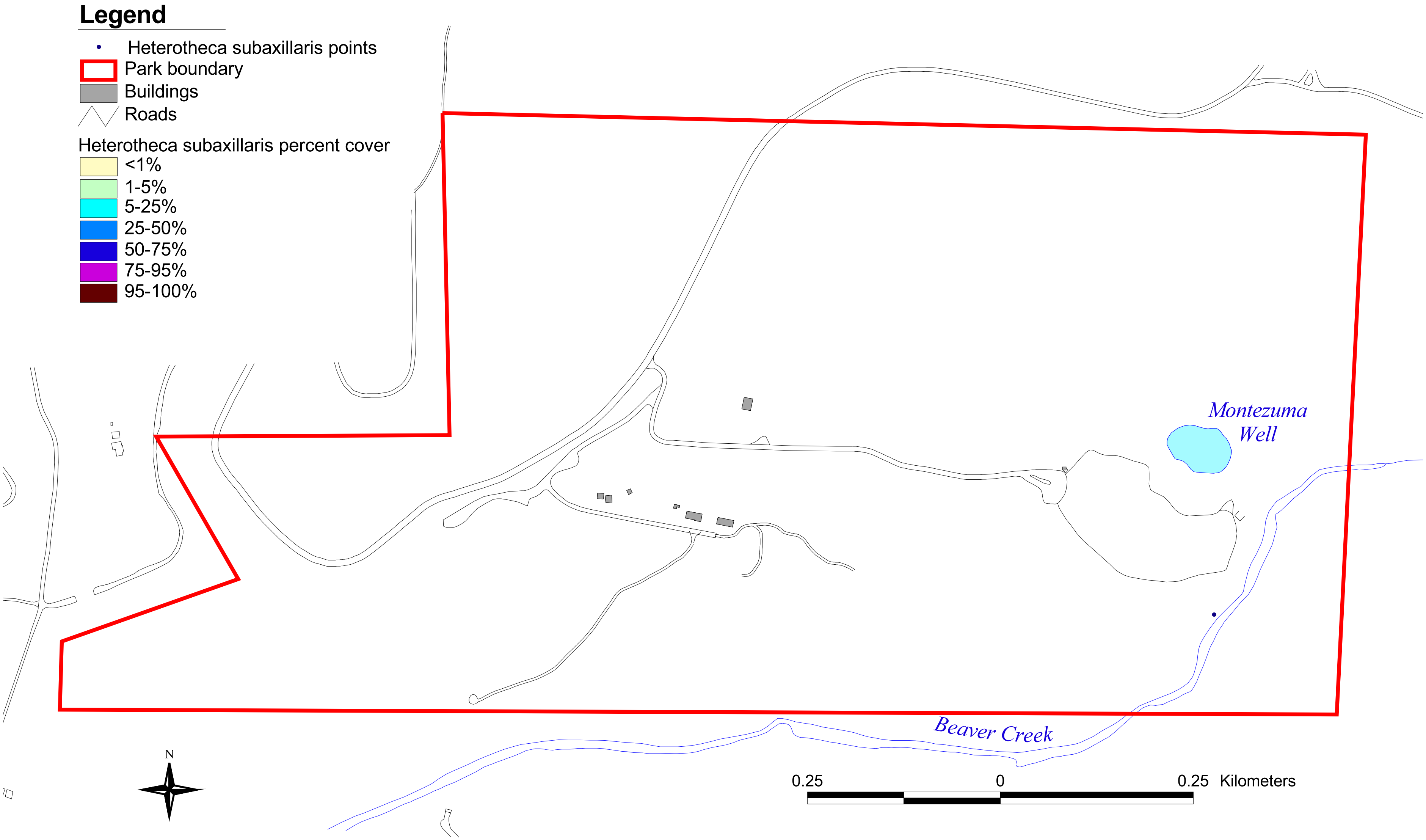
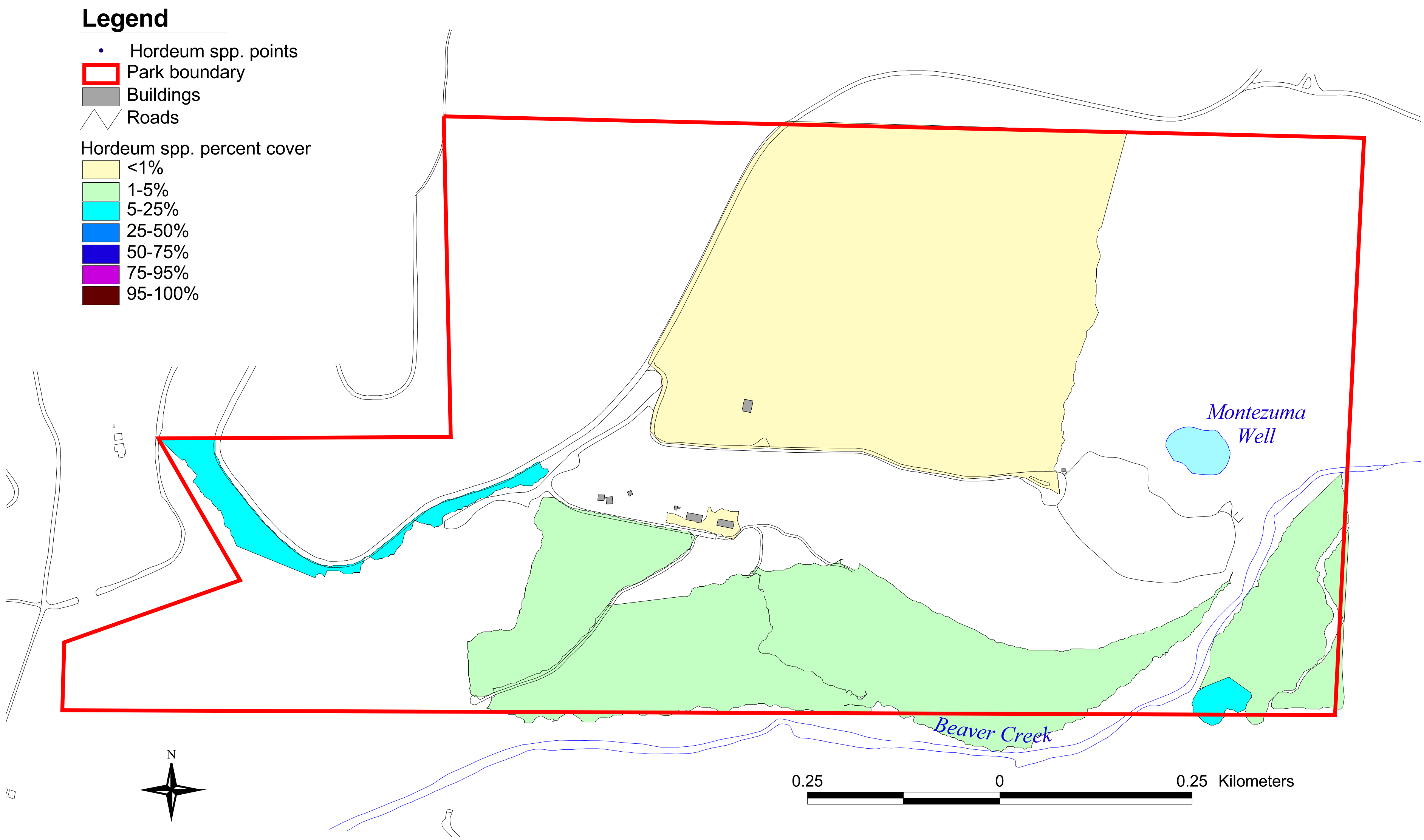
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Heterotheca subaxillaris
Montezuma Castle National Monument, Well Unit, AZ



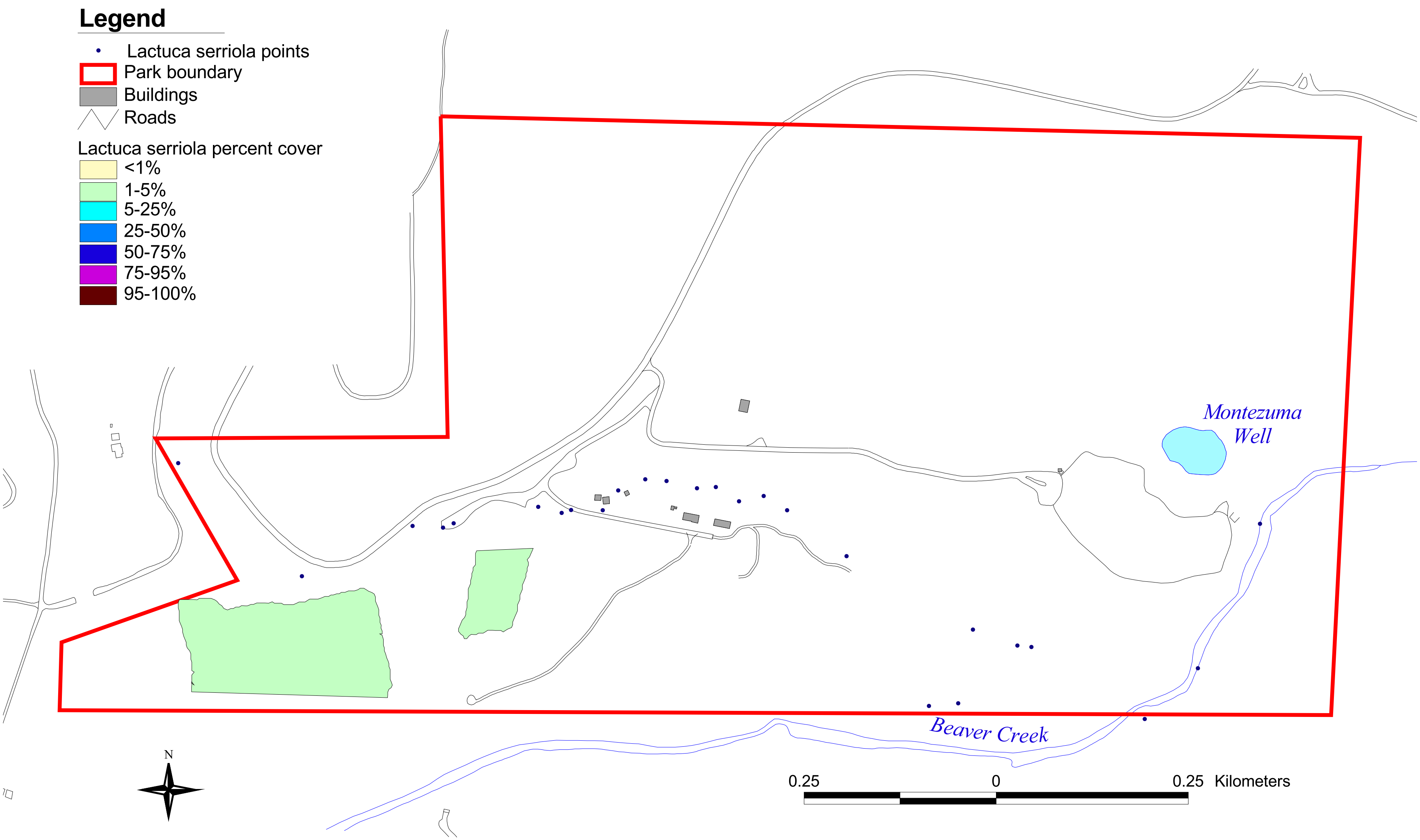
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Hordeum spp.
Montezuma Castle National Monument, Well Unit, AZ



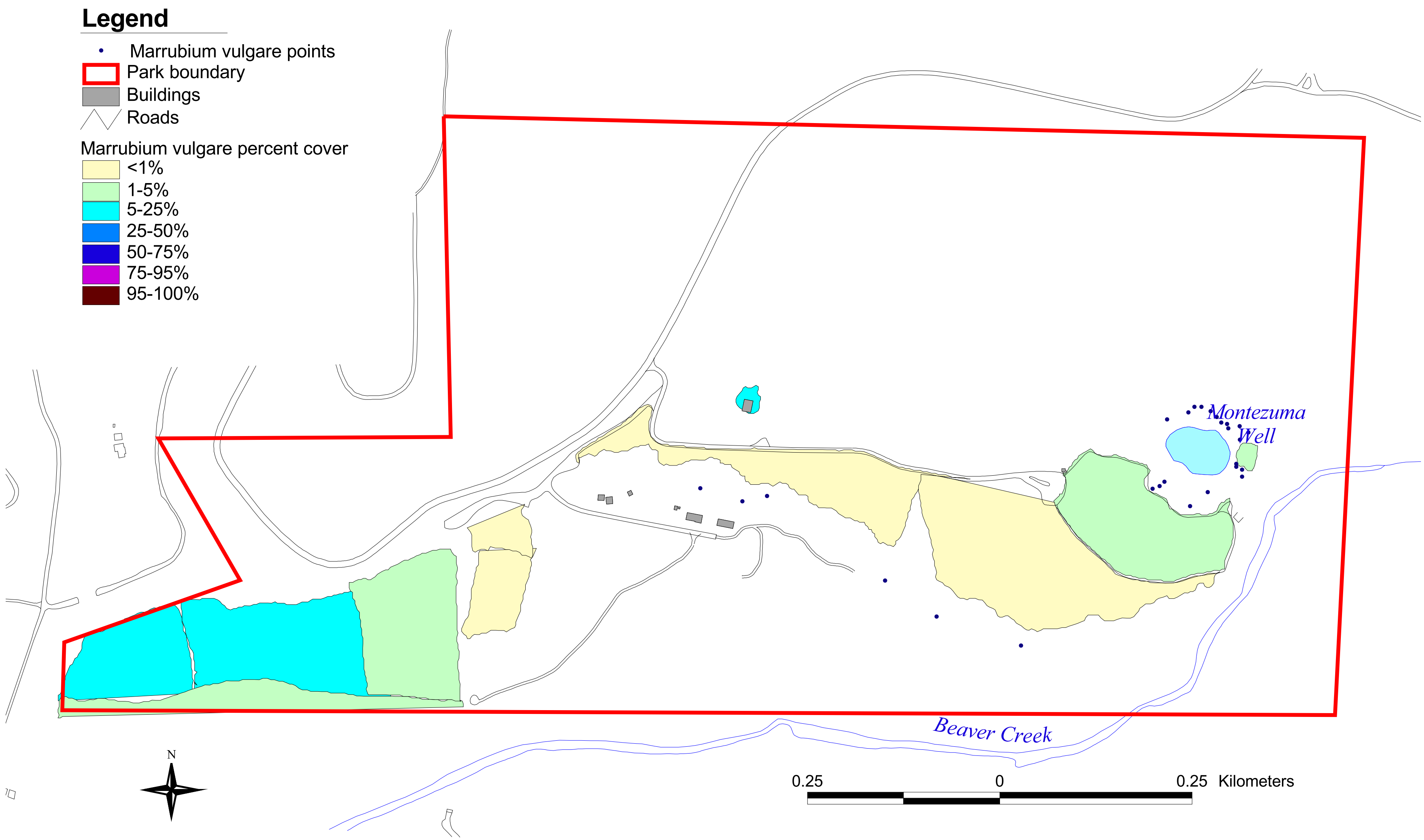
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Lactuca serriola
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Marrubium vulgare
Montezuma Castle National Monument, Well Unit, AZ



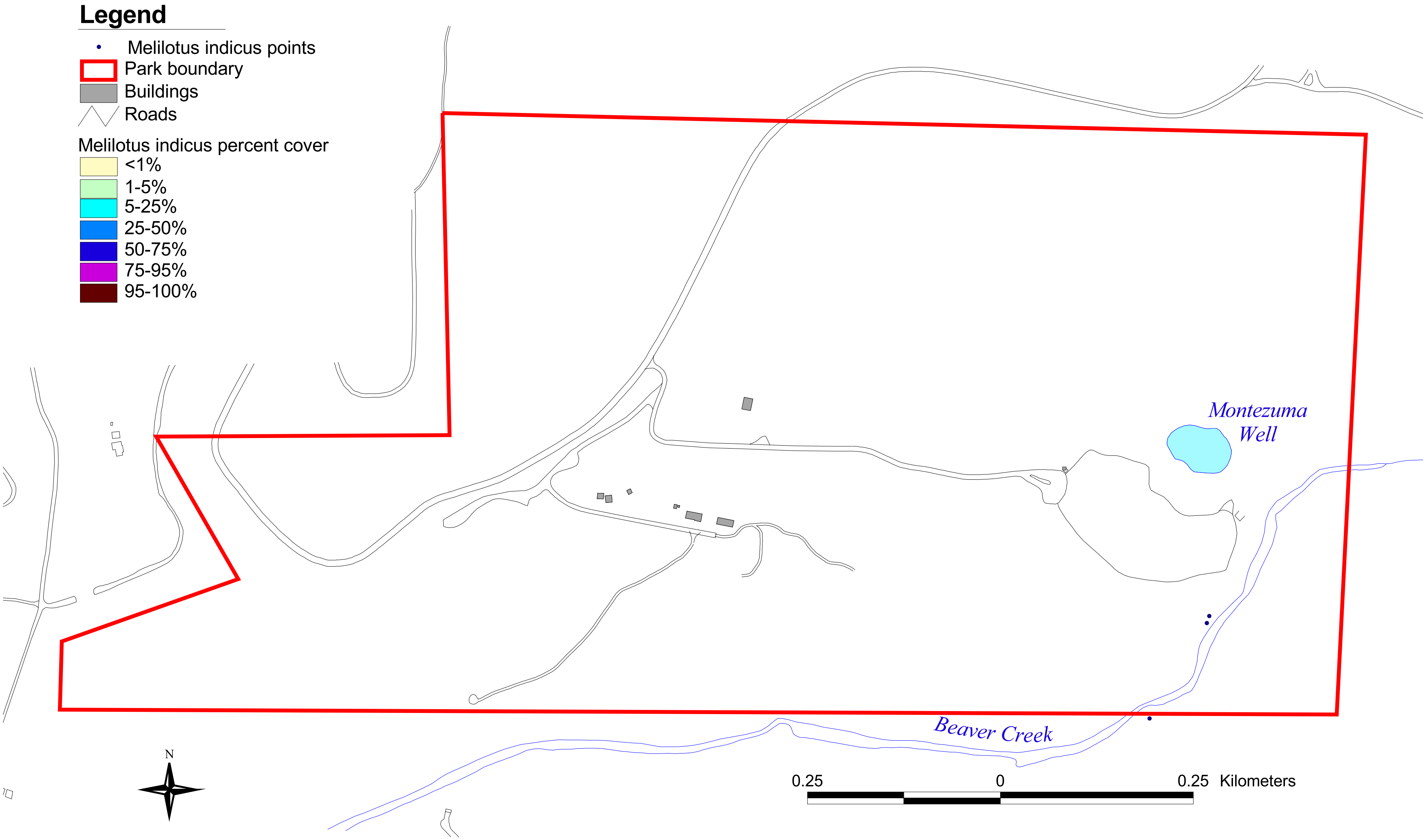
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Melilotus albus
Montezuma Castle National Monument, Well Unit, AZ

Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Melilotus indicus

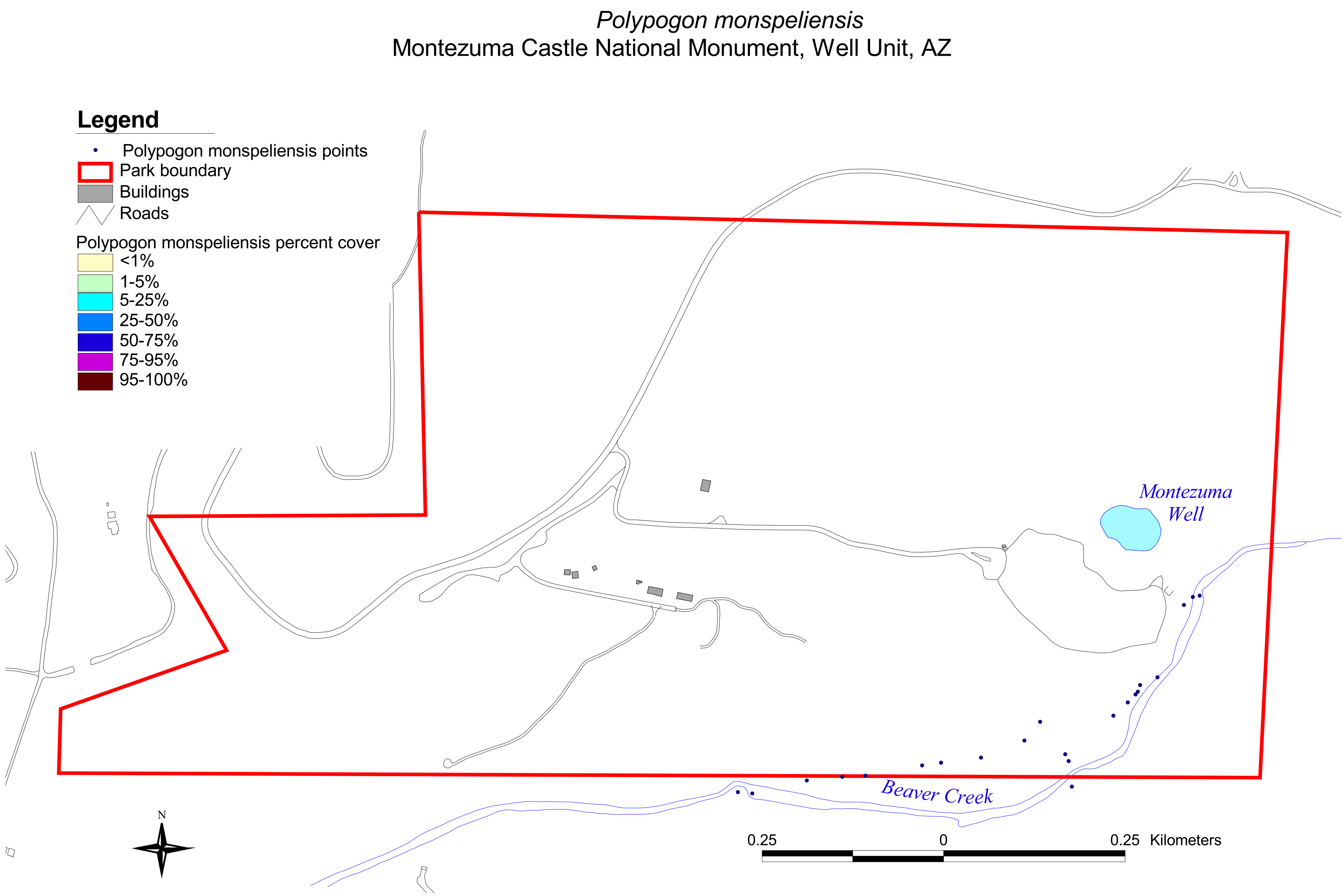
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.

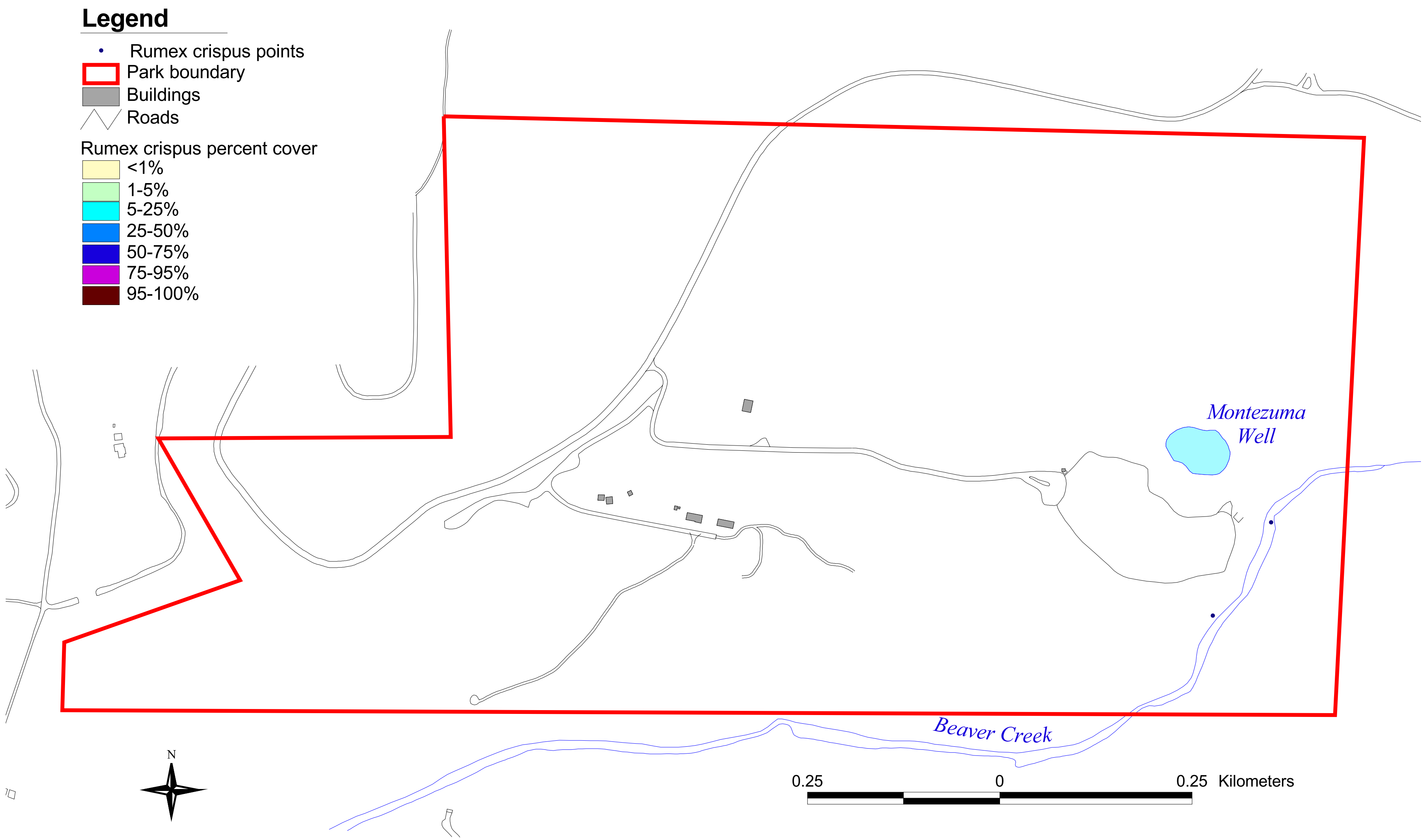
Data projection: UTM NAD83

Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Rumex crispus
Montezuma Castle National Monument, Well Unit, AZ



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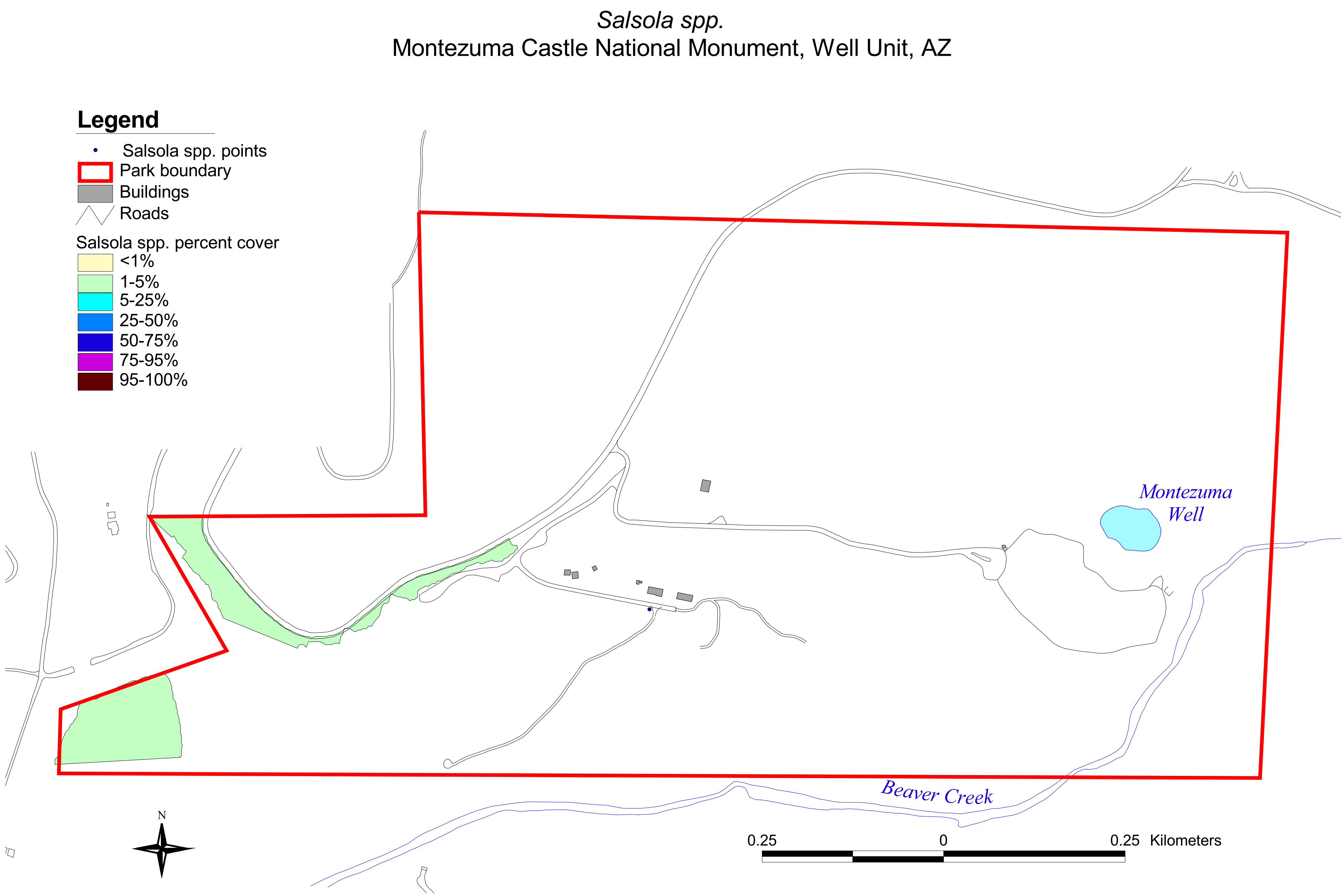
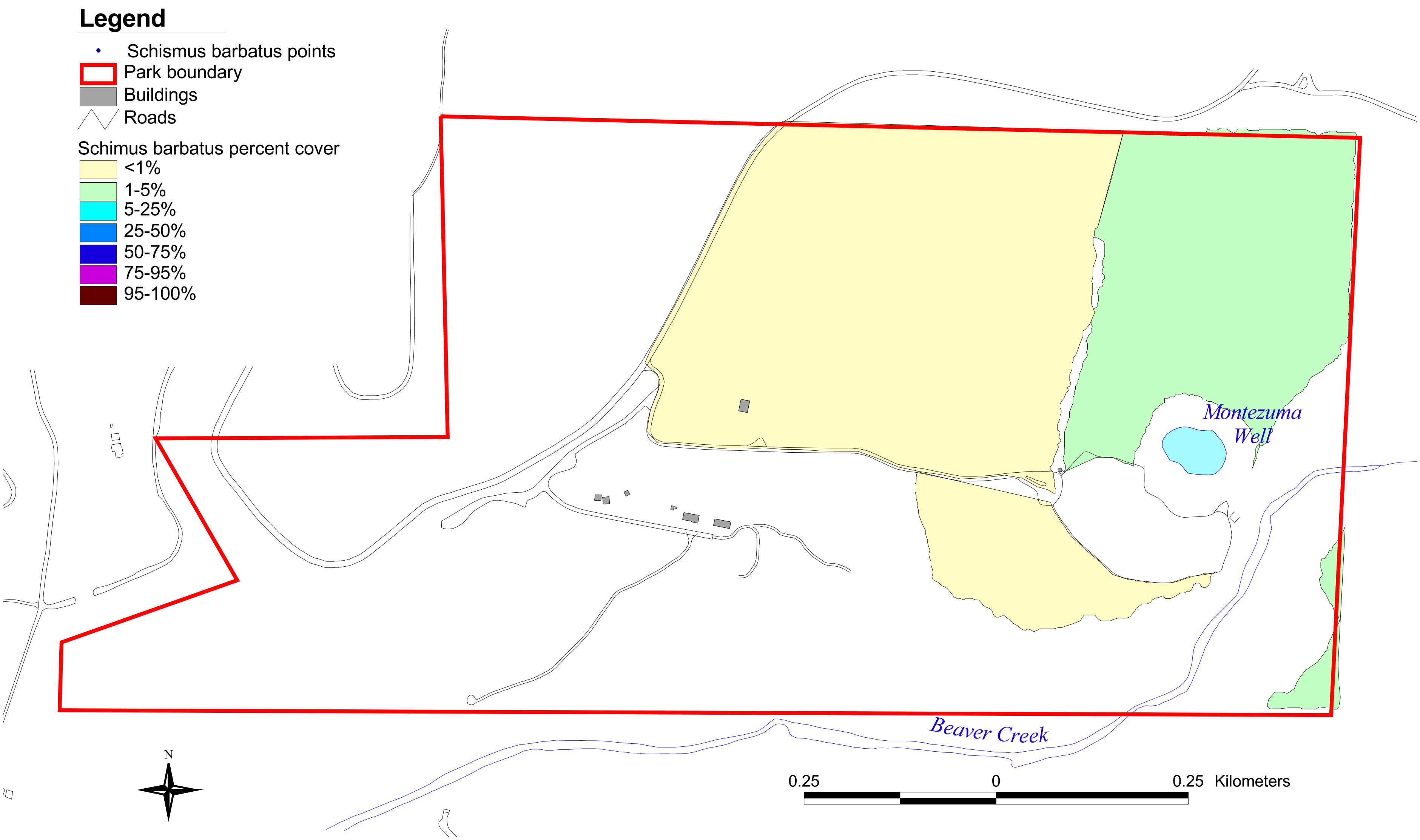
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.



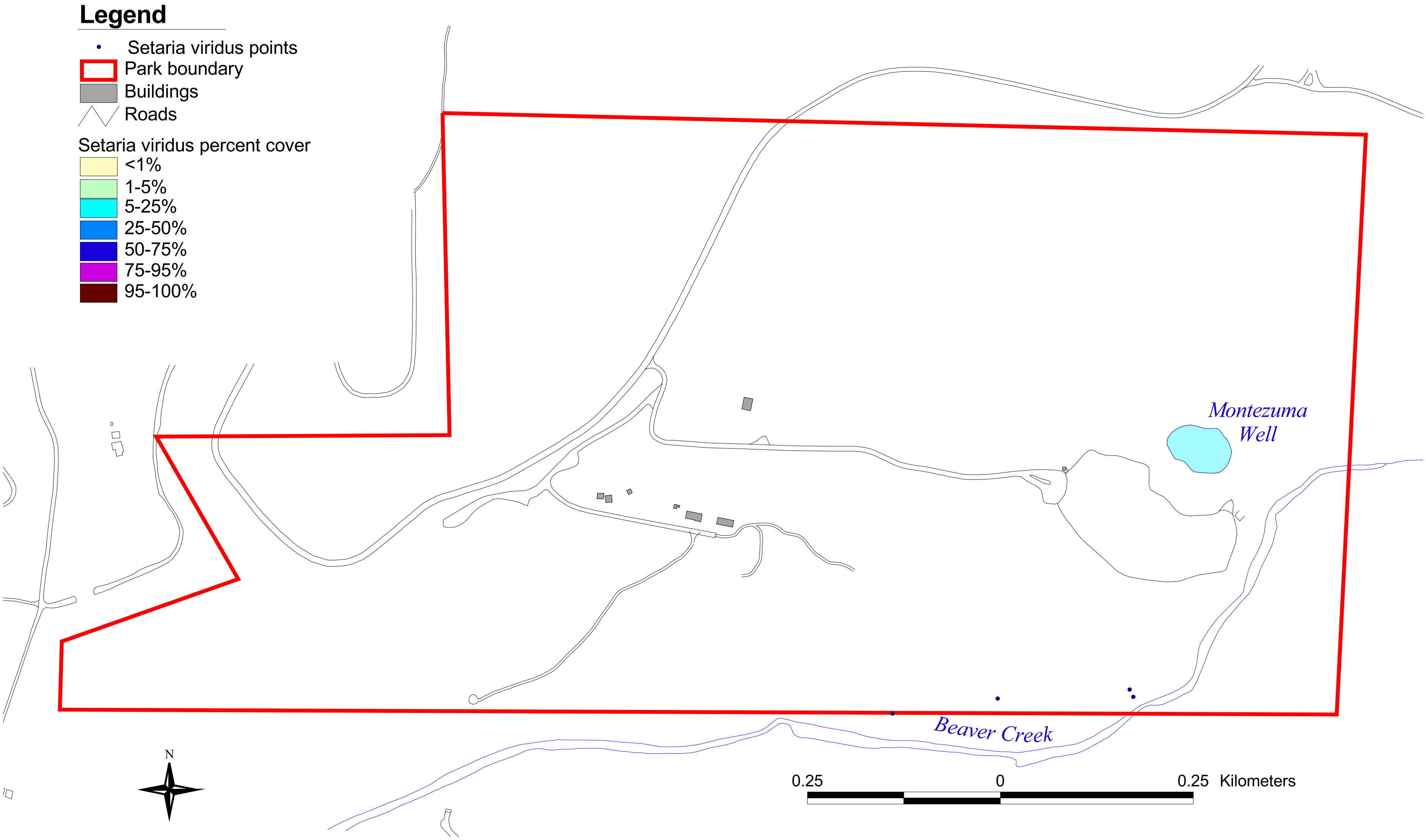
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Schismus barbatus
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

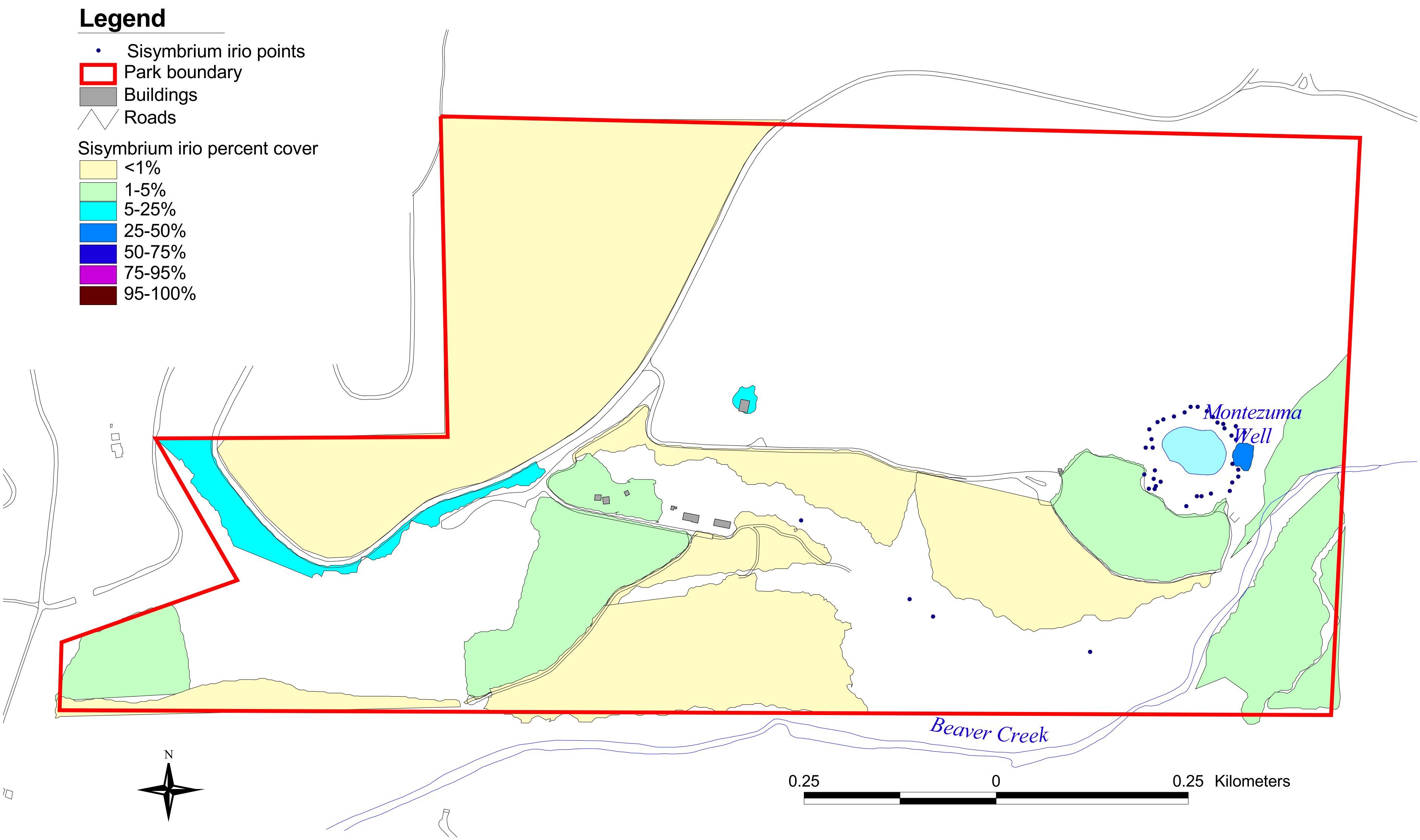
Setaria viridus
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

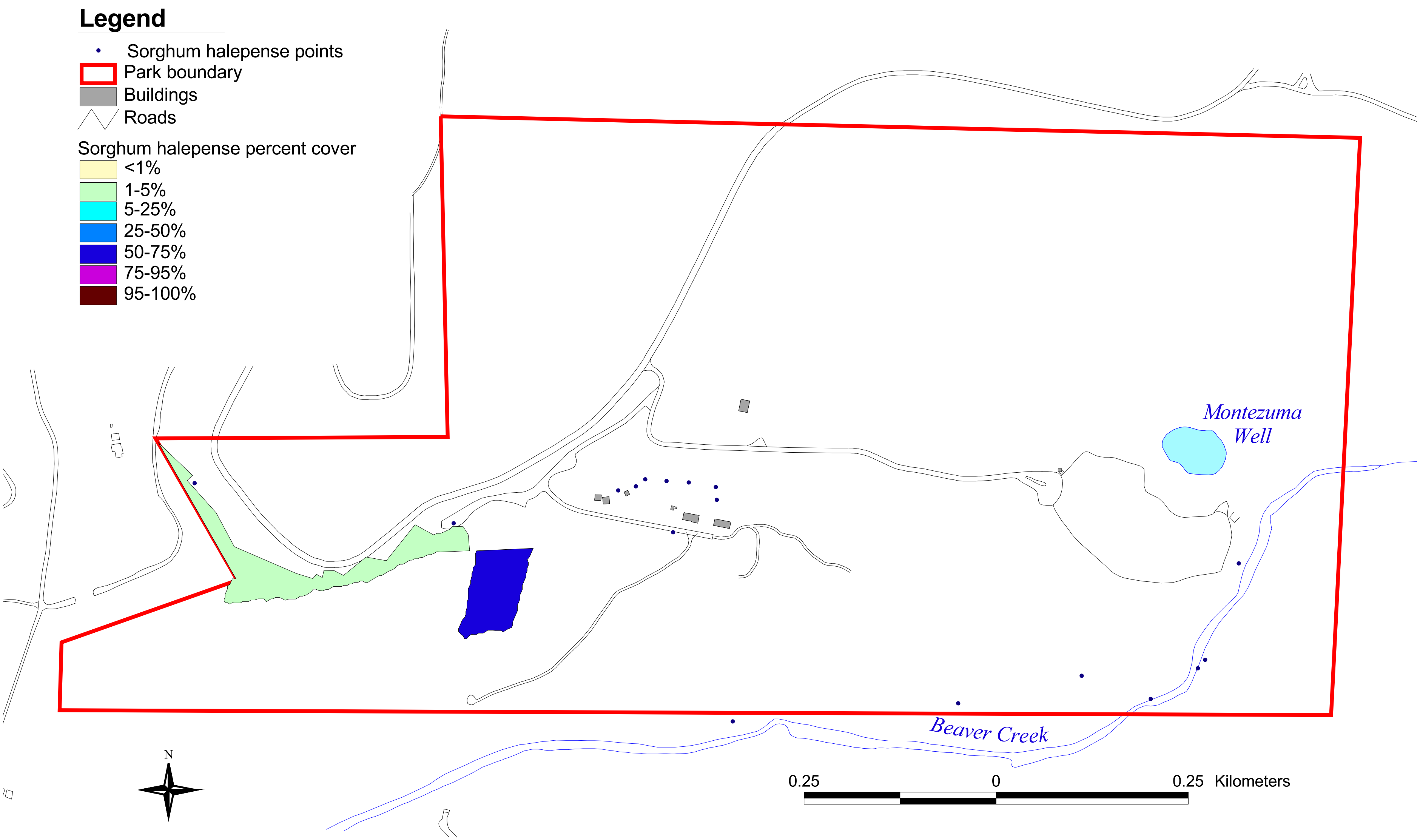
Sisymbrium irio

Montezuma Castle National Monument, Well Unit, AZ



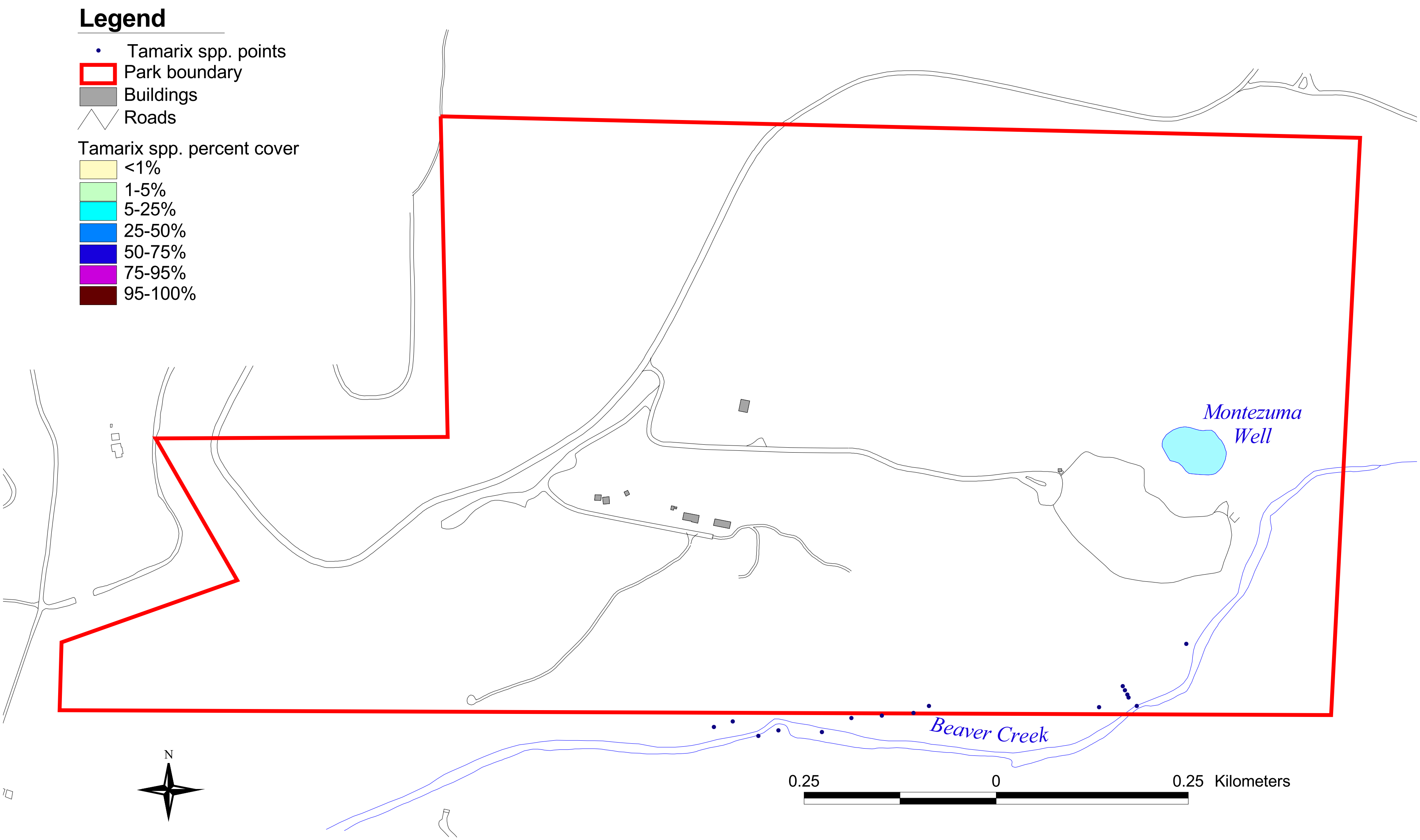
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Sorghum halepense
Montezuma Castle National Monument, Well Unit, AZ



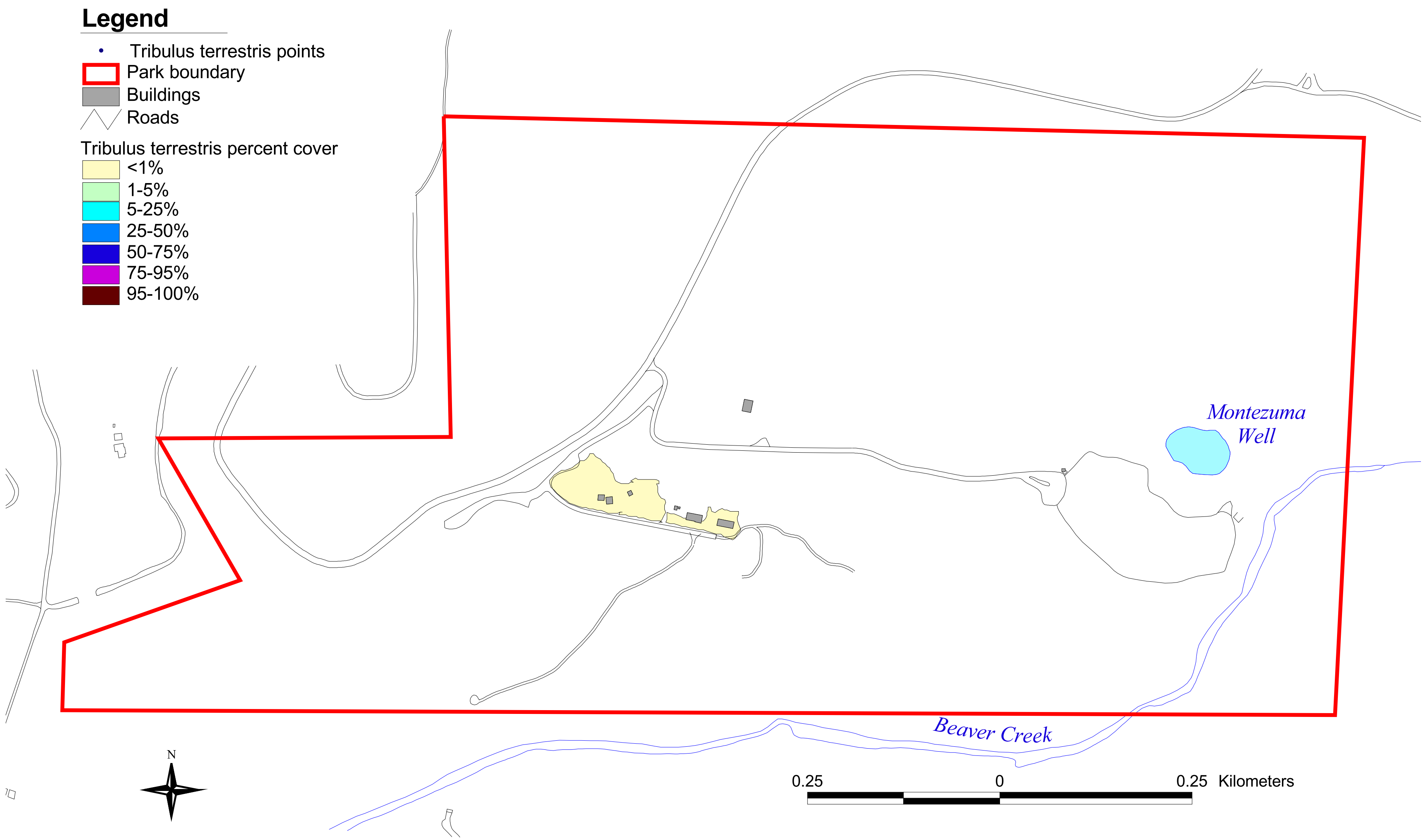
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Tamarix spp.
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Tribulus terrestris
Montezuma Castle National Monument, Well Unit, AZ



Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
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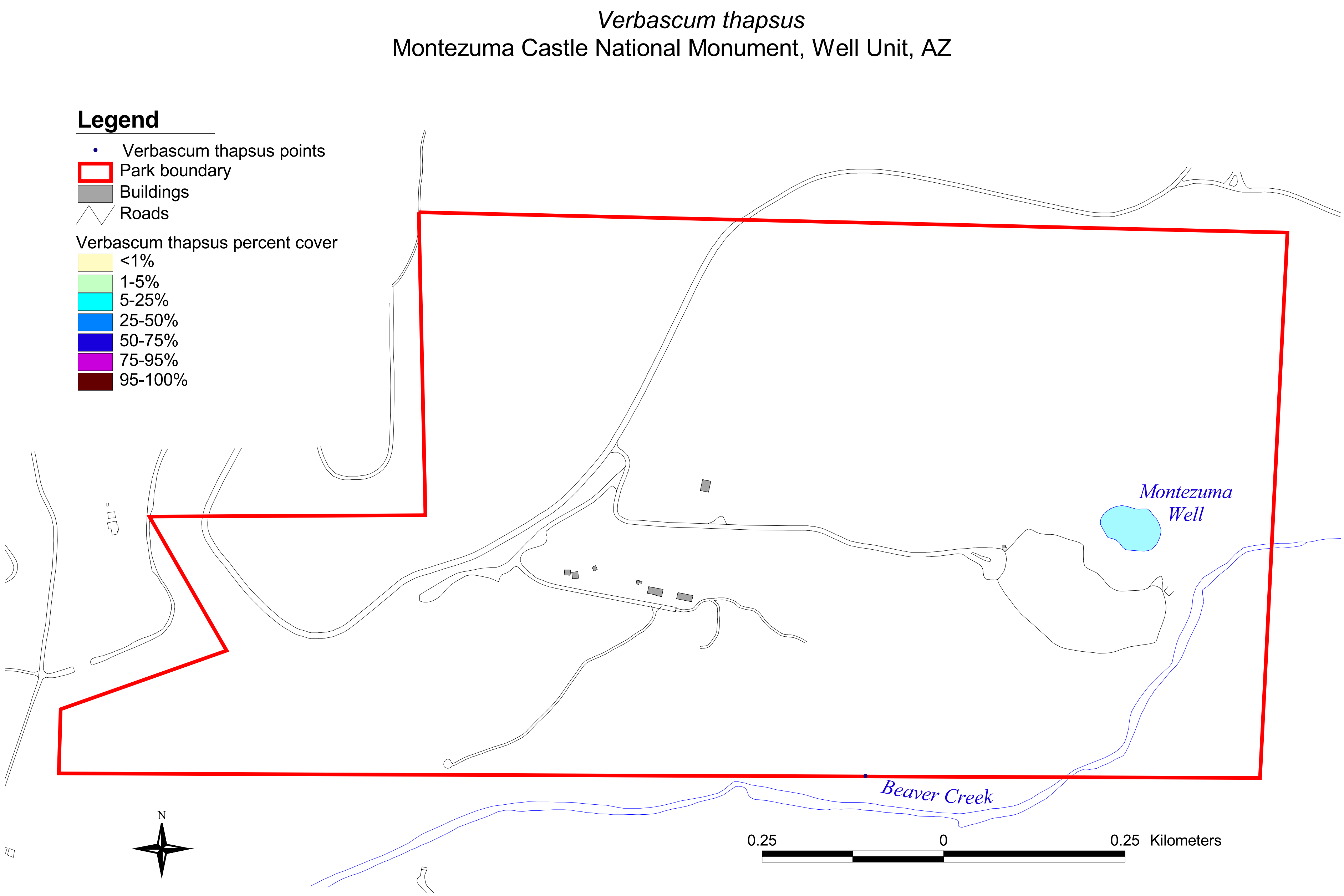
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

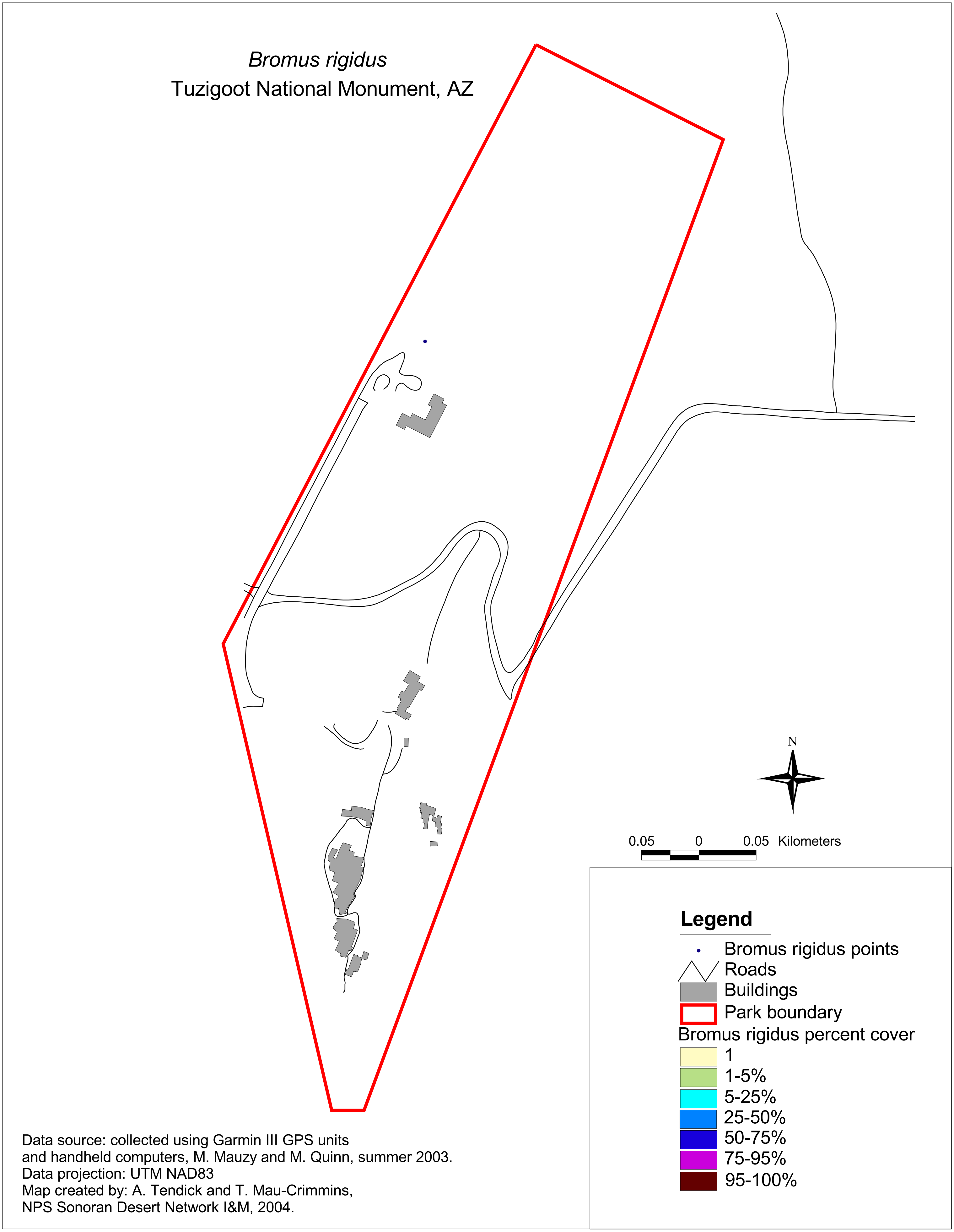


Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

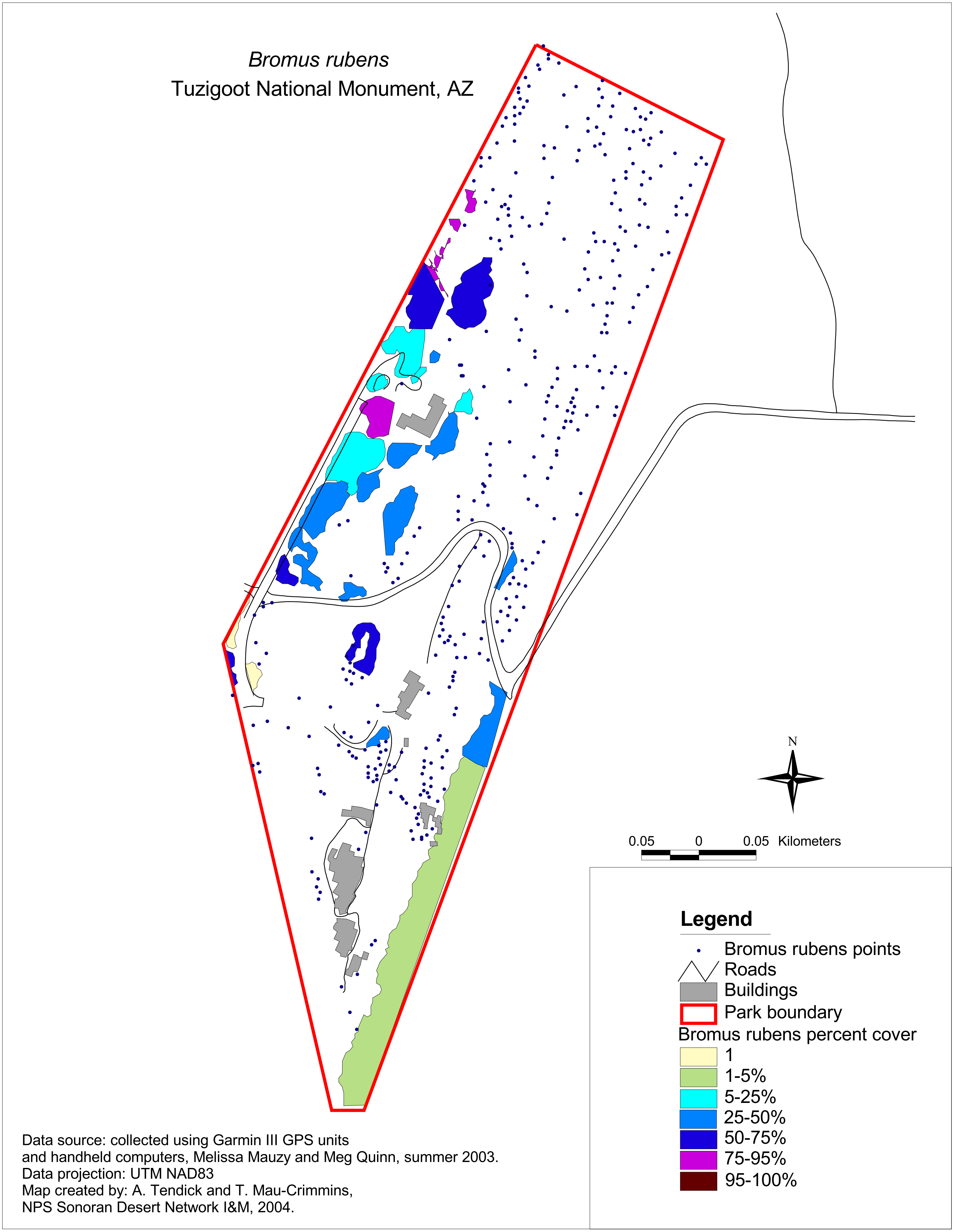
Xanthium strumarium
Montezuma Castle National Monument, Well Unit, AZ

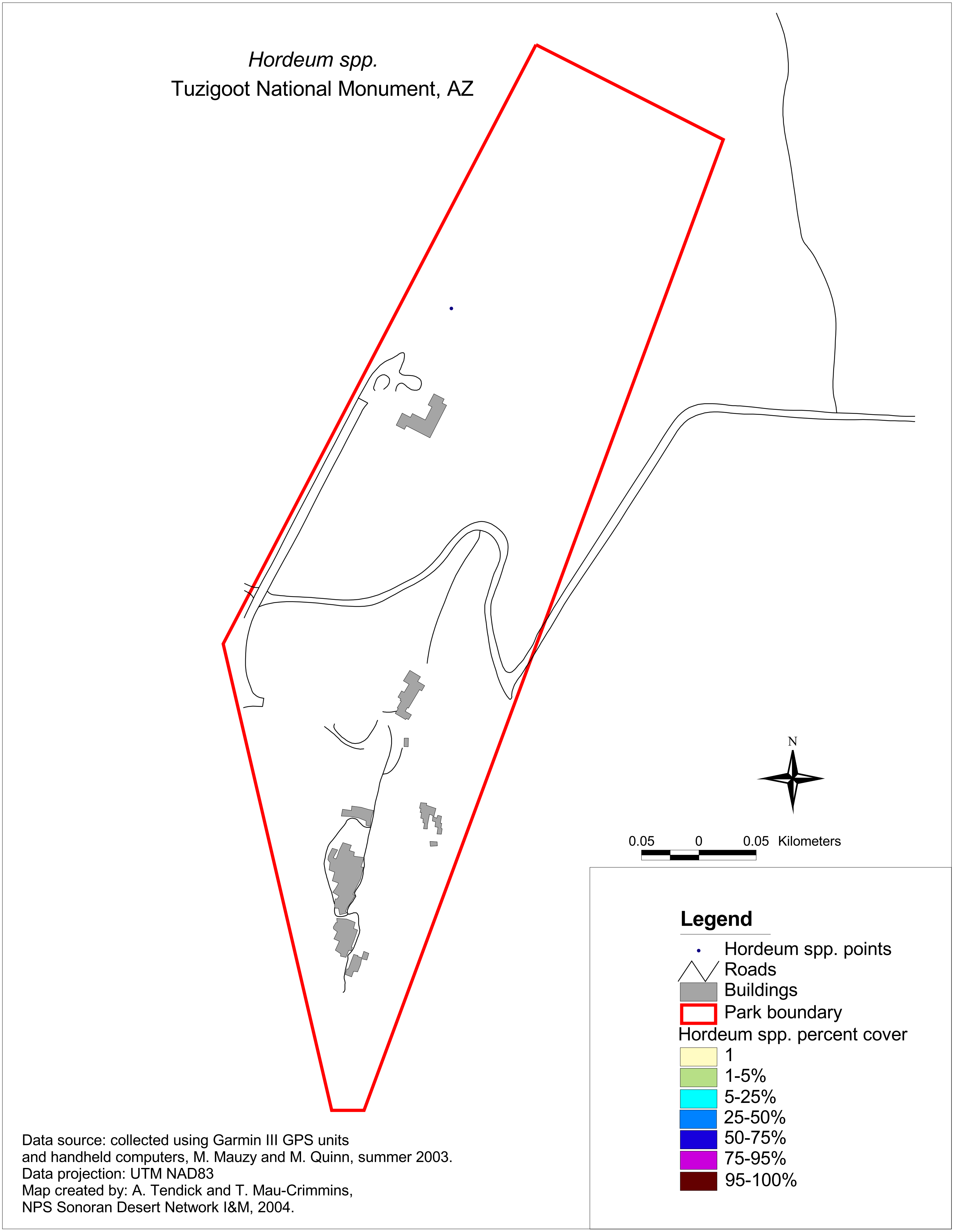
Data source: collected using Garmin III GPS units and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins, NPS Sonoran Desert Network I&M, 2004.

Bromus rigidus
Tuzigoot National Monument, AZ

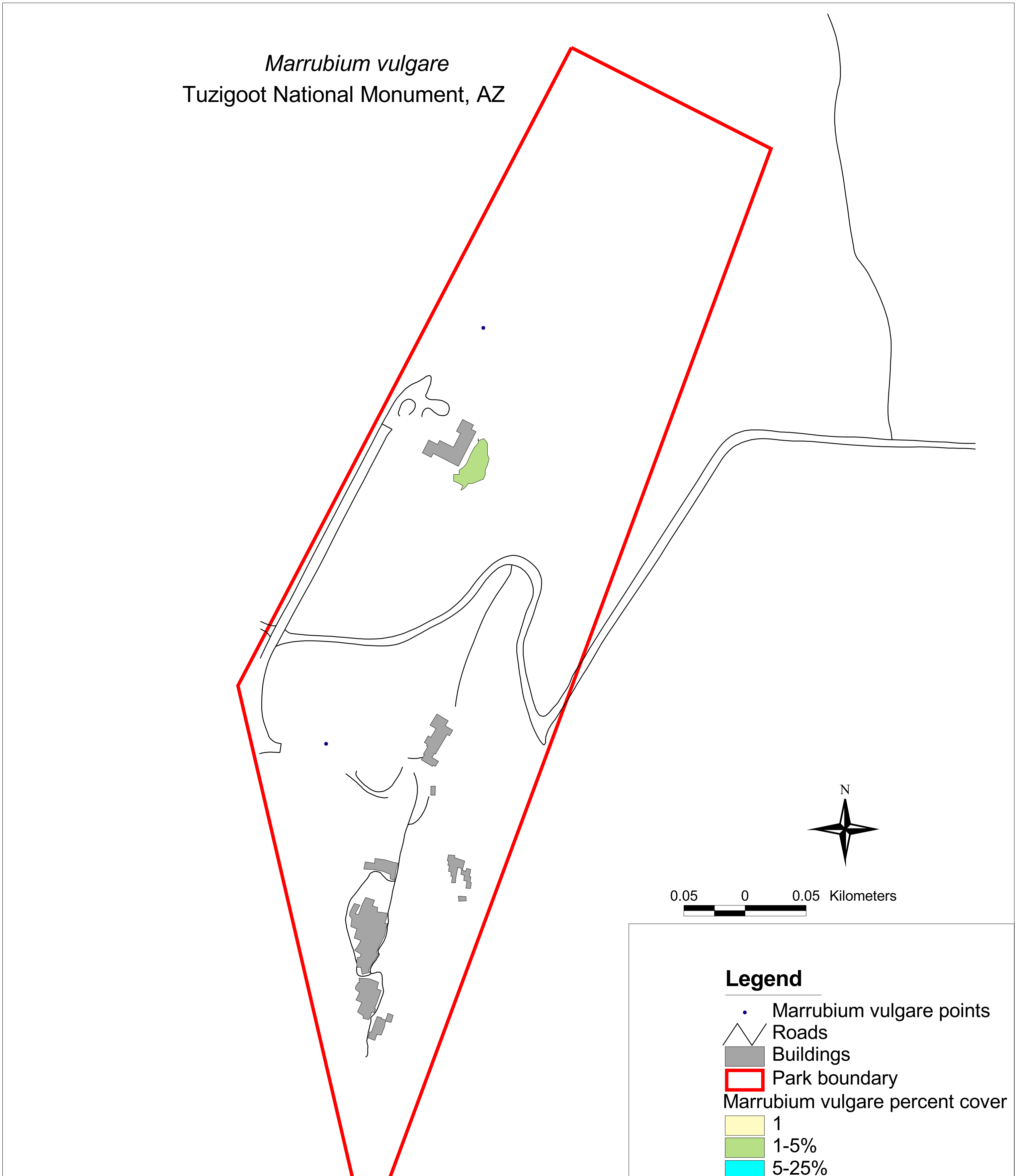


Data source: collected using Garmin III GPS units
and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins,
NPS Sonoran Desert Network I&M, 2004.


Bromus rubens
Tuzigoot National Monument, AZ
N
0.05 0 0.05 Kilometers
Legend
Bromus rubens points
Roads
Buildings
Park boundary
Bromus rubens percent cover
1
1-5%
5-25%
25-50%
50-75%
75-95%
95-100%
Data source: collected using Garmin III GPS units
and handheld computers, Melissa Mauzy and Meg Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins,
NPS Sonoran Desert Network I&M, 2004.


Hordeum spp.
Tuzigoot National Monument, AZ
N
0.05 0 0.05 Kilometers
Legend
Hordeum spp. points
Roads
Buildings
Park boundary
Hordeum spp. percent cover
1
1-5%
5-25%
25-50%
50-75%
75-95%
95-100%
Data source: collected using Garmin III GPS units
and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins,
NPS Sonoran Desert Network I&M, 2004.

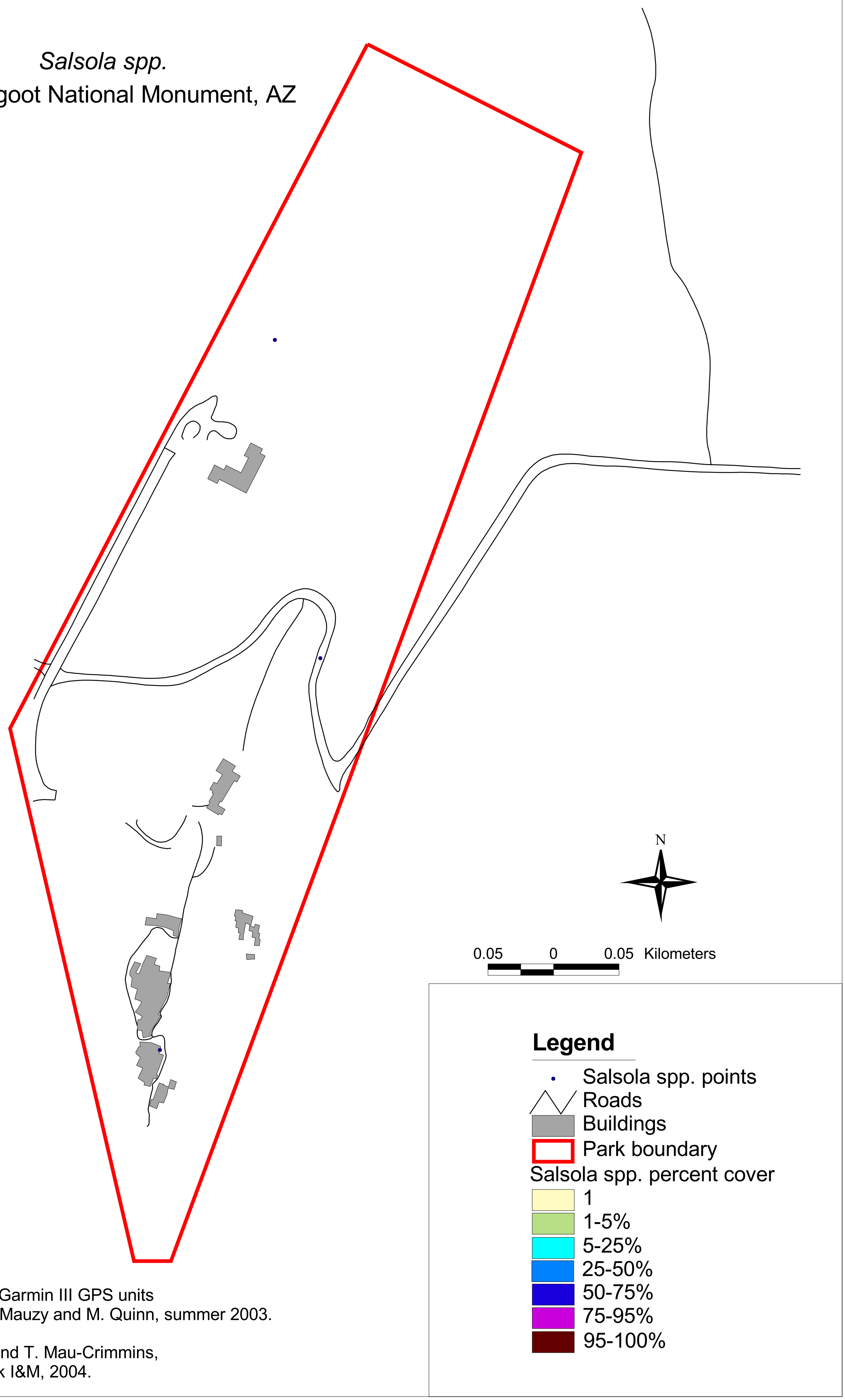
Marrubium vulgare
Tuzigoot National Monument, AZ



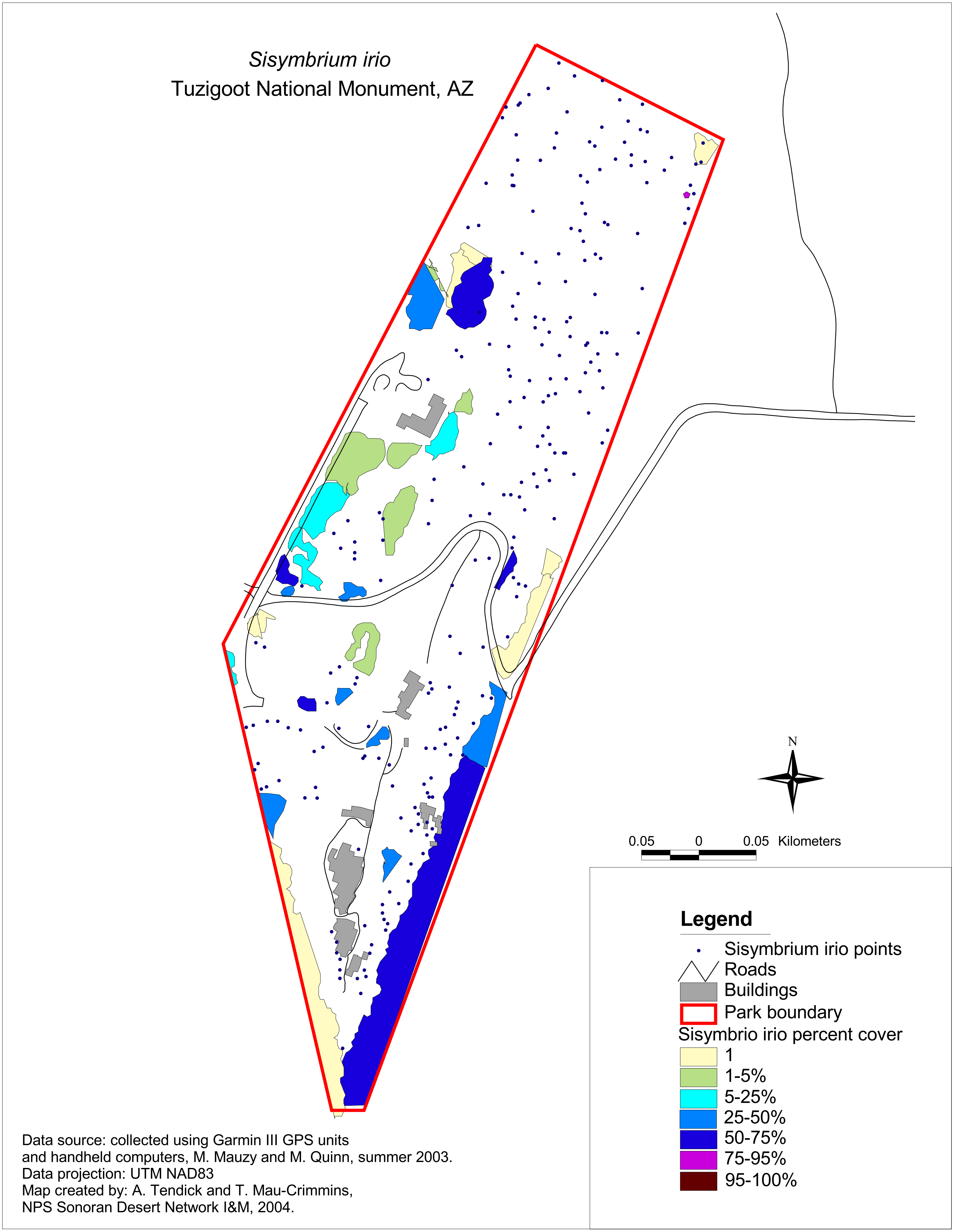
Data source: collected using Garmin III GPS units
and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins,
NPS Sonoran Desert Network I&M, 2004.

Salsola spp.

Tuzigoot National Monument, AZ



Data source: collected using Garmin III GPS units
and handheld computers, M. Mauzy and M. Quinn, summer 2003.
Data projection: UTM NAD83
Map created by: A. Tendick and T. Mau-Crimmins,
NPS Sonoran Desert Network I&M, 2004.


Sisymbrium irio
Tuzigoot National Monument, AZ
N
0.05 0 0.05 Kilometers
Legend
Sisymbrium irio points
Roads
Buildings
Park boundary
Sisymbrio irio percent cover
1
1-5%
5-25%
25-50%
50-75%
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Data source: collected using Garmin III GPS units
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NPS Sonoran Desert Network I&M, 2004.